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Subsurface Fish Handling

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On the cover: Handling
fish beneath the sea. NMFS photo.

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Disease Risks Associated with Importation of Nonindigenous Marine Animals

CARL J. SINDERMANN

Introduction

Considerations of introduced marine organisms usually involve concerns that may be categorized as:

1) Those related to possible ecological changes (especially changes in habitat, competition, and predation);

2) Those related to possible genetic influences on native species; or

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ABSTRACT—Transfers and introductions of marine species have occurred and are occurring on a worldwide basis, largely in response to perceived needs of expanding aquaculture industries. Greatest interest is in salmon (cage rearing and ocean ranching), shrimp, and bivalve mollusks, although other organisms are being considered. Such movements of animals carry an associated risk of moving pathogens into areas where they did not occur previously, possibly resulting in infections in native species. Many case histories of the effects of introduced pathogens and parasites now exist—enough to suggest that national and international action is necessary. Viral pathogens of shrimp and salmon, as well as protozoan parasites of mollusks and nematode parasites of eels, have entered complex "transfer networks" developed by humans, and have been transported globally with their hosts in several well-documented instances. Examining the records of transfers and introductions of marine species, incomplete as they are, permits the statement of emerging principles—foremost of which is that severe disease outbreaks can result from inadequately controlled or uncontrolled movements of marine animals.

3) Those related to the introduction of pathogens not endemic to the receiving area.

Of these concerns, much attention has been directed to the third—disease and its implications in introductions. This is entirely logical, since disease may have profound effects on populations, especially those of economic value, and since some marine disease problems have proven to be remarkably intractable for extended periods.

In this paper I consider several case histories that illustrate emerging concepts about introduced diseases and then offer recommendations to reduce the risks of disease when marine animals are inserted into new environments by human acts. The case histories discussed are: 1) Viral diseases of shrimp, 2) viral diseases of salmon, 3) rickettsial disease of coho salmon, 4) oyster diseases, 5) *Perkinsus* (protozoan) disease of bay scallops, and 6) eel nematodes.

Viral Diseases of Shrimp

Growing worldwide interest in penaeid shrimp culture has led to extensive transfers and introductions of species with desirable culture characteristics. Six lethal viral pathogens have been recognized. Of these, IHHNV (infectious hypodermal and hematopoietic necrosis virus) is one of the most serious. This highly lethal pathogen poses a serious threat to shrimp culture (Lightner et al., 1983a; Bell and Lightner, 1983, 1984). Found in cultured *Penaeus stylirostris*, *P. monodon*, *P. japonicus*, and *P. vannamei*, and in wild-caught *P. monodon* brood stock in Southeast Asia (Lightner et al., 1989), it has been introduced into aquaculture facilities in Hawaii, Florida, Texas, Tahiti, Philippines, Guam, and elsewhere. *Penaeus stylirostris* is especially susceptible, and extensive mortalities from IHHNV infections have been reported. *Penaeus vannamei* harbors subacute infections that may cause stunting (Kalagayan et al., 1991). Experimental infections with IHHNV have been achieved in *P. setiferus*, *P. aztecus*, and *P. duorarum*.

IHHNV disease was first recognized in 1981 in Hawaiian shrimp culture facilities rearing *P. stylirostris* introduced from Panama (Lightner et al., 1983b). Soon after, the role of *P. vannamei* as a carrier of the virus was recognized. The virus can be observed in juveniles and adults, where its effects are found, but not in larvae or postlarvae. Of major concern is the possibility of infection of native populations by the introduced pathogen, even though there is yet no definitive evidence demonstrating that this has happened. Strict quarantine of imports is extremely important, as is care in selection of IHHNV-free sources of brood stock.

The most recent event in the continuing shrimp virus story is the spread, in 1989 and 1990, of IHHNV to the developing shrimp aquaculture industry of northwest Mexico, with consequent major production losses (Lightner et al., 1992).

Some appreciation for the extent of the viral problem in shrimp can be seen by examining the movement of stocks during the past two decades from centers of research and commercial development in Hawaii, Tahiti, Panama, Japan, and elsewhere. Such extensive movements create a transfer network, often operating without adequate disease inspection. IHHNV and other viruses have already entered this network

and are being introduced into farms far from their original geographic range (Fig. 1).

This concept of a transfer network is extremely important. Humans are busy creating these complex transfer networks with many cultured marine species, but especially with shrimp, oysters, salmon, and eels. Severe pathogens are entering these networks and moving along them, killing substantial numbers of introduced and native stocks. As pointed out by Lightner (1990), "It is apparent that if an unrecognized pathogen entered any facility in the transfer network, the mechanism exists for it to be rapidly transferred to several other facilities. Further, if the pathogen remained undetected, it could be easily introduced into all of the facilities in the transfer network."

Viral Diseases of Salmon

Sporadic attempts to introduce Pacific salmon, *Oncorhynchus* spp., to Atlantic waters have been made for more than a century (Solomon, 1979, 1980; Harache, 1992). Long-term establishment of runs and reproductive populations have been unsuccessful to date—in the sense that continued existence of runs depends on annual importation of eggs from Pacific sources.

Despite this record of failure, attempts still continue, adding new approaches such as cage culture in coastal waters and private ocean ranching dependent on hatchery production of young fish. Coho salmon, *O. kisutch*, have been the focus of cage culture efforts; pink salmon, *O. gorbuscha*, and chum salmon, *O. keta*, are species of choice for ocean ranching, principally because they may be released to open waters at an early age. France has had an active program importing coho for sea cage culture (Fig. 2) (Harache, 1992).

Several large-scale introductions of Pacific salmon have been made in Atlantic waters (Fig. 3). The Soviet Union transferred large numbers (up to 35 million per year) of pink salmon eggs from the Kamchatka Peninsula and Sakhalin Island to the Kola Peninsula near northern Norway during 1957–77 (Grinyuk et al., 1978). Some self-sustaining populations appear to have developed, although there is doubt about their long-term persistence in the absence of continued importation of eggs from the Pacific. Some straying to northern Norway occurred (Bjerknes and Vaag, 1980).

The State of New Hampshire had a long-term (1960–90) program of importation of coho salmon eggs. There was limited evidence for some natural spawning, with low survival (Stolte, 1974) but permanent runs have not been established.

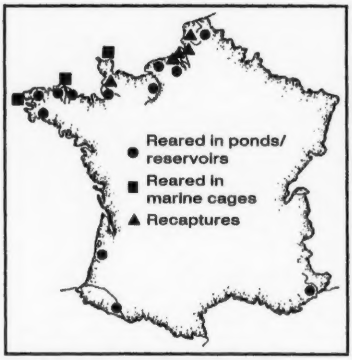

Figure 2.— Locations in France where nonindigenous coho salmon were reported during 1970–80 (modified from Euzenat and Fournel, 1981).

In all of these Pacific salmon introductions, primary concerns have been competition with native Atlantic salmon, *Salmo salar*, and the possible importation of diseases. Diseases of greatest recent concern are infectious hematopoietic necrosis (IHN) and viral hemorrhagic septicemia (VHS)—both lethal viral diseases:

1) IHN now occurs in Italy and France (Bovo et al., 1987; Hattenberger-Baudouy and de Kinkelin, 1988), probably introduced with rainbow trout, *O. mykiss*, eggs

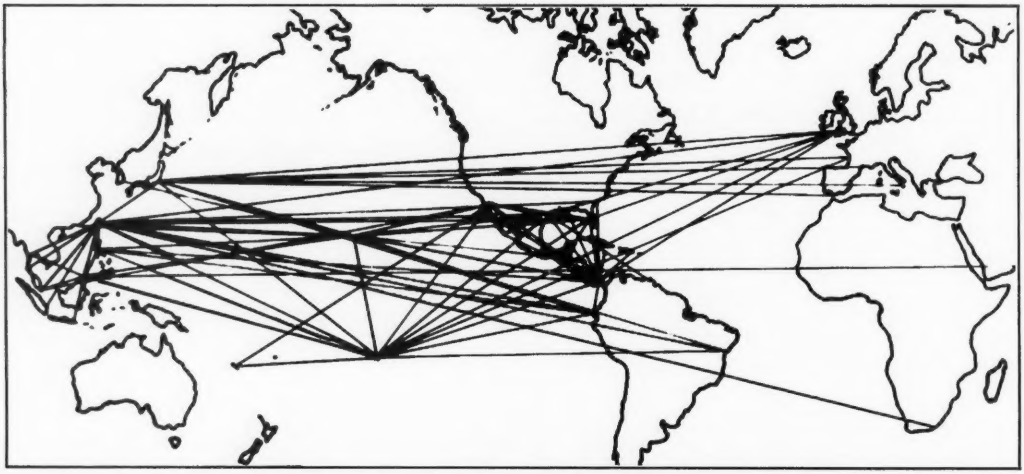

Figure 1.— A "shrimp transfer network" prepared by and courtesy of D. V. Lightner (1990) from published and unpublished reports of shrimp stock movements.

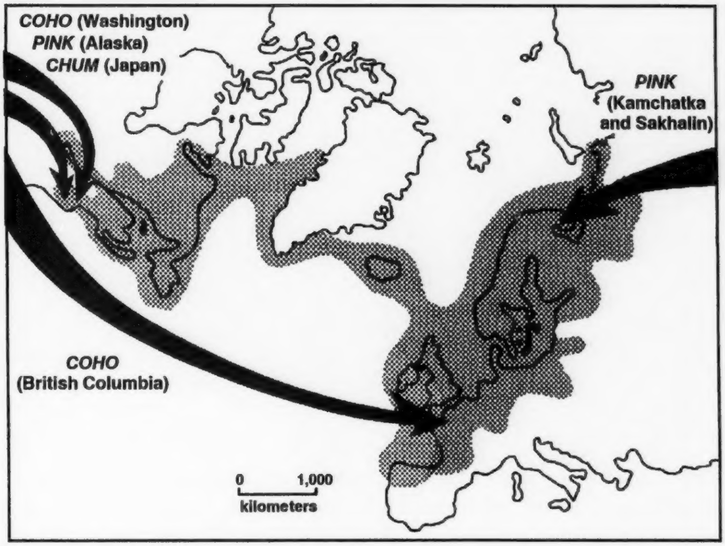

Figure 3.— Distribution of Atlantic salmon, with arrows indicating principal locations of recent Pacific salmon introductions (modified from MacCrimmon and Gots, 1979).

from the west coast of United States, where the pathogen is common.

2) IHNV was introduced into Hokkaido, Japan, probably with the transfer of sockeye salmon, *O. nerka*, eggs from Alaska in 1968. The virus spread rapidly to Honshu island where it has become enzootic. IHNV has also been isolated from rainbow trout mortalities in Taiwan, Korea, and the People's Republic of China, probably as a result of the importation of rainbow trout or eggs from Japan (Chen et al., 1985).

3) VHS—common in Europe, especially in rainbow trout—was reported in salmonids from the Pacific coast of North America in 1988 (Brunson et al., 1989; Hopper, 1989; Winton et al., 1989). Initial concerns were that the virus had been imported from Europe as a consequence of aquaculture activities. However, recent studies have disclosed genetic and virulence differences in VHS virus isolates from Pacific salmon as compared with European isolates (Bernard et al., 1991; Oshima et al., 1991; Winton et al., 1991), and VHS virus was isolated in 1990 and 1991 from Pacific cod caught in Alaska—possibly suggesting a reservoir for North American strains of the virus in marine species (Meyers et al., 1991).

The possible introduction of severe pathogens with movements of salmon leads directly to another concept—that all introductions of pathogens or parasites are "accidental," even though the introduction of host animals can be deliberate. This fact is often overlooked in discussions of "intentional" vs. "unintentional" introductions, and even in drafting legislation concerning introduced species. Emphasis must therefore be on control and exclusion of diseased animals and infected resistant carriers—through programs similar to those that have evolved to control disease dissemination in terrestrial animals.

Rickettsial Disease of Coho Salmon

During the past decade, a number of salmonids, including the coho salmon, have been introduced to coastal waters of Chile for net-pen culture. Beginning in winter 1989, mass mortalities of up to 90% of stocks occurred in some locations in southern Chile (Bravo and Campos, 1989) and an epizootic of a rickettsial organism, *Piscirickettsia salmonis*, has been identified as the causative agent (Cvitanich et al., 1990; Fryer et al., 1990; Branson and Diaz-Munoz, 1991; Fryer et al., 1992; Garcés et al., 1991).

Although infectious agents from North America, such as the bacterium *Renibacterium salmoninarum*, which causes kidney disease, were introduced with imports to Chile from the northern hemisphere, the rickettsial disease is believed to have its source in native aquatic species of Chile (Fryer et al., 1990). Interesting aspects of the microorganism are that it was not reported in fish held in fresh water, and was first observed 6–12 weeks after transfer of fish to saltwater rearing pens. Horizontal transmission of the pathogen was achieved experimentally in both fresh and salt water (Cvitanich et al., 1991). In addition to coho salmon, other salmonid species, notably Atlantic salmon and chinook salmon, *O. tshawytscha*, and rainbow trout, have been found to be susceptible to the rickettsial infection.

Fryer et al. (1990), who isolated the organism from fish introduced to Chile and studied it in Chile and in Oregon, made the following and very interesting comment:

"In vivo studies are planned to test this hypothesis [that the rickettsia isolated is the causative agent of the coho salmon disease]. The potential pathogenicity of the organism, its apparent virulence, and the fact that it is not known to occur outside of Chile dictate that these studies be conducted in the area where the disease is endemic. For these reasons, the agent will be returned to Chile for infection experiments in coho salmon."

This statement by Fryer et al. is in my opinion the embodiment of another important concept—albeit one difficult to implement in practice:

Studies of a pathogen should be conducted, insofar as possible, in the area where the disease it causes is enzootic; the pathogen should not be transported to nonenzootic areas for in vivo stud-

ies, simply because of the availability of expertise and facilities in those areas. Reality suggests that some exceptions might be considered. Isolation wet-laboratories, designed for the express purpose of studying exotic aquaculture pathogens in their natural or experimental hosts, could be used when studies are not feasible in areas where the pathogen in question is enzootic. Establishment of several regional and/ or international isolation wet-labs (with funding for construction and operation) would help to reduce risks from introduced pathogens.

This concept is based on the likelihood that an introduced pathogen may be accidentally disseminated outside the laboratory or experimental facilities if it is transported for in vivo studies in experimental fish populations outside the area where it currently occurs. Such dissemination could involve accidental infection of commercially valuable native fish stocks with resulting mass mortalities.

Unfortunately, in the case history described in this section—rickettsial infection in coho salmon—the stricture against in vivo experimentation with the pathogen outside its enzootic area does not seem to have been followed. Cvitanich et al. (1991) reported infection experiments in seawater aquaria apparently conducted in Oregon, although the actual site of the study was not specified in their report—except that it was a "non-fish rearing quarantine facility." The conditions defining quarantine have become just too variable in many marine infection studies to justify confidence in absolute exclusion of introduced pathogens from the natural waters of recipient countries. Exceptions to this admittedly severe restriction might be made only for experiments in facilities where absolute control of pathogens and of experimental animals can be guaranteed—where containment is equivalent to that of facilities involved in experimental studies using pathogens of public health significance.

(Note: The principle elaborated here may have some merit, but the example used—the Chilean rickettsia—shows signs of collapsing. Recent information (Hoskins[1]) suggests that a rickettsial organism, serologically the same as the Chilean isolate, may have been seen as early as 1970 in several salmonid species from British Columbia, but not noted there as a virulent pathogen.)

Oyster Diseases

Oysters have long been known to be subject to mass mortalities, but the past three decades have been especially troublesome. Major and widespread mortalities have occurred and in some cases are still occurring in the United States, Europe, and Japan. Specific pathogens, often viruses or protozoans, have been identified as causative organisms in most instances.

Oysters have also been moved from place to place probably more frequently than any other marine animal group, providing excellent vehicles for dissemination of pathogens and parasites. Transfer networks comparable to those known for shrimp have been created—especially for the Pacific oyster, *Crassostrea gigas* (Chew, 1990), and important pathogens have been transported, sometimes by complex pathways (Elston et al., 1986).

One of the largest experiments in the introduction of marine species was the importation to the coast of France of the Pacific oyster, *C. gigas*, during 1966–77. Introduced as seed and as adults from Japan and British Columbia, *C. gigas* replaced declining populations of the so-called "Portuguese oyster," *C. angulata*, which had been the industry mainstay for decades. The Pacific oyster prospered; reproduction was successful in some parts of the French coast, and production now exceeds 150,000 t (Grizel and Héral, 1991).

What have we learned from this massive French experiment from a disease perspective? A remarkable series of epizootics in the two native species of oysters occurred simultaneously with the Pacific oyster introductions. Beginning in 1966, the native oyster *C. angulata* died in large numbers from a viral gill disease (Comps and Duthoit, 1976; Comps et al., 1976). By 1973, when the epizootic subsided, populations of *C. angulata* had been largely destroyed, and the introduced Pacific oyster, *C. gigas*, had replaced them in most grow-out areas. During the same period, populations of the European flat oyster, *Ostrea edulis*, were also affected severely by epizootic disease (Comps, 1970; Comps et al., 1980). Beginning in 1968, the protistan parasite *Marteilia refringens* affected oyster growing areas. As that epizootic waned in the mid-1970's, *Bonamia ostreae*, another protistan parasite, increased to epizootic proportions and further reduced populations of *O. edulis*. This epizootic continues at present, and, as a result, *O. edulis* culture is at a standstill. There is some evidence that the pathogen *Bonamia* was introduced to France with imports of *O. edulis* seed from a California hatchery that had been rearing offspring of a stock that originated decades earlier in the Netherlands, and was first introduced into Connecticut in the 1950's (Elston et al., 1986).

The occurrence within a single decade of three major oyster epizootics, each with accompanying mass mortalities, is unique in the long and well-documented history of oyster culture. Also unique is the scale of importation of a replacement species (*C. gigas*) during this same period. Despite extensive research by European pathologists, the role that this massive introduction of a nonindigenous species may have played in disease outbreaks in the native species is unknown, and a direct relationship has not been demonstrated, although suggestions have been made and some associations proposed—like the one describing the history of *Bonamia*.

The worldwide experience with introduced *C. gigas* has indicated that at least three categories of disease risks exist.

1) One risk is from the known pathogens of the species, which may or may not be transferred to the native species. For *C. gigas*, five pathogens are known:

[1]Hoskins, G. 1992. Salmonid rickettsial agent identified in British Columbia. Pacific N.W. Fish Health Prot. Comm., Vancouver (December 1991), Meet. Highlights, Newsl. March 1992, p. 1.

a) An iridovirus that causes "larval velar disease" (and which is similar to the virus that killed *C. angulata* in France);
b) A bacterium, *Nocardia* sp., which causes fatal inflammatory bacteremia;
c) An ascetosporan protozoan parasite, *Marteilioides chungmuensis*, which affects ova;
d) A presumptive ascetosporan protozoan, *Mikrocytos mackini*, which causes "Denman Island disease" in *C. gigas* introduced on the west coast of North America, but yet unreported from native stocks in Japan (Farley et al., 1988); and
e) A parasitic copepod, *Mytilicola orientalis*, found in the gut.

2) Another risk is from other organisms with unknown pathogenicity to *C. gigas*, but possibly pathogenic to other species of oysters (an example of this category would be the reported occurrence of a haplosporidan parasite, similar to *Haplosporidium nelsoni*, a severe pathogen of American oysters, in *C. gigas* from Korea, but not known to be pathogenic to *C. gigas*).

3) A third risk arises from still other organisms, rare or unrecognized in populations of *C. gigas*, that may be pathogenic to related species of oysters (examples suggested, without supporting evidence, are *Marteilia* and *Bonamia* in flat oysters, *O. edulis*).

The uncertainties present in this listing are reflections of the relative youth of marine pathology as a scientific discipline. Many diseases of oysters and other species are unknown or poorly understood, so they would not form part of normal inspection protocols.

Closer to home, the native east coast American oyster, *C. virginica*, has been hard hit in the Middle Atlantic states by epizootics of two protozoan pathogens that began in the late 1950's and still persist. Oysters are frequently shipped from state to state, and documentation is good for the transfer of one of the diseases ("MSX" disease, caused by the protozoan *Haplosporidium nelsoni*) to states where it had been previously unknown (Massachusetts, South Carolina).

The transfer network for some cultured species can be extraordinarily complex, and some pathways can be quickly obscured or never revealed. An excellent example is seen in the attempt by Elston et al. (1986) to trace the origin of the flat oyster pathogen, *Bonamia ostreae*, that has destroyed most European production of that species beginning in 1979. Export of infected seed oysters to France from a hatchery on the California coast was proposed as the immediate source of the disease. That hatchery had received brood stock (presumably infected) from the Milford Laboratory in Connecticut which, in turn, had received the original introductions from the Netherlands in the 1950's. Somewhere in the early part of this chain of events, possibly at Milford, *Bonamia* infected the introduced species. The severe consequences of bonamiasis for European culture of flat oysters, *Ostrea edulis*, have been described in detail by Balouet et al. (1983), Figueras (1991), Hudson and Hill (1991), McArdle et al. (1991), Stewart (1991), and Van Banning (1991).

This and other examples illustrate the reality that unless early scientific attention is directed to the occurrence of a new parasite or microbial pathogen, the history of its introduction and subsequent dissemination may be quickly lost. Thus, the entire episode will become forever a matter of speculation and conjecture (examples include the origin of *H. nelsoni* (MSX) disease in oysters of Delaware Bay and the origins of recent oyster disease outbreaks in France). As Stewart (1991) has stated, ". . . although many diseases are suspected to have been introduced in one manner or another, irrefutable evidence is usually lacking."

Perkinsus (Protozoan) Disease of Bay Scallops

The previous section on oyster diseases illustrates some of the complexities and uncertainties of disease transmission through transfer networks. One melancholy fact not yet pointed out, however, is that pathological examination of candidate species for introduction may not always disclose the presence of known disease agents and is unlikely to identify unknown agents except by chance. Known disease agents may have cryptic stages or may be extremely rare in the samples examined, and they may elude recognition. Pathological effects of undescribed pathogens may be labeled "idiopathic lesions" or "nonspecific granulomas" and thus escape deserved attention.

An excellent case history of just such an event can be found in the introduction into Canadian waters of a parasitic protozoan—a species of *Perkinsus*, with its host, the bay scallop, *Argopecten irradians*. Histopathological examination of the original imports from United States in 1979–80 disclosed only chlamydia-like and rickettsial infections and nonspecific granulomas (Morrison and Shum, 1982, 1983). The scallops were reared in quarantine for three generations before field release. Then in 1989, after open-water culture had begun, hatchery brood stocks were examined and a *Perkinsus* agent was recognized in the formerly described "granulomas," and subsequently described as *P. karlssoni* by McGladdery et al. (1991). A similar or identical organism had been seen much earlier in bay scallops from U.S. waters (Ray and Chandler, 1955), and more recently by Karlsson (1990). This episode illustrates very well the principle that disease risks from introductions are never zero, even when adequate regulatory and inspection systems exist. Canada has been diligent in developing regulations and a regionally based infrastructure to control introductions of nonindigenous species; yet despite this concern and action, the pathogen, *P. karlssoni*, was introduced into Canadian waters and is now present in Canadian bay scallop populations. The pathogenicity of *P. karlssoni* to bay scallops has yet to be clearly established, however, and interspecies transmission to other molluscs has not been observed (McGladdery et al., 1991).

Eel Nematodes

A recent and expanding disease problem in Europe is the spread of nematode worms, *Anguillicola crassus*,

in native European eel, *Anguilla anguilla*, populations. The worms were introduced with shipments of live Japanese eels, *A. japonica*, from Asia. They are large bloodsucking organisms that occlude the swim bladder (Fig. 4), cause emaciation, result in mortality in holding pens, and interfere with spawning migrations (Koie, 1991).

Infection of native eels was first noticed in Germany in 1982, probably as a consequence of release of infected eels shipped from Taiwan in 1980 (Koops and Hartmann, 1989). The parasites now occur in most of the countries of Europe (Netherlands, Denmark, Poland, England, Spain, Greece, etc.), often with high prevalences and intensities. Infections can be acquired as early as the elver stage, in which an acute inflammatory reaction occurs in the swim bladder; small crustaceans serve as intermediate hosts.

Population expansion following introduction has been rapid. In one river in England (where the worm was first reported in 1987), prevalence levels of 100% and average intensities of 6.7 worms were attained in 1 year (Kennedy and Fitch, 1990). An active network of eel transfers in Europe has undoubtedly favored the rapid expansion of nematode populations throughout the subcontinent. Eel farms have been seriously affected, with reduction in growth rates, emaciation, and mortalities of up to 65% in captive populations.

Like many introduced parasites, *Anguillicola* will continue to spread by natural movements of hosts, but principally by human transport for stocking aquaculture ponds and for market within and across national boundaries. The rapid spread of this introduced parasite through the native eel populations of Europe provides excellent illustration of at least two more concepts:

1) Once an introduced pathogen is established in a marine/catadromous/anadromous fish population, it is difficult if not impossible to restrict or control its further spread in natural waters. (Control in aquaculture facilities is, however, feasible.)

2) The colonization potential of many parasites in new environments is predictable on theoretical grounds, but not the relative importance of different methods of dissemination (especially human-assisted movements of infected hosts).

Concepts and Principles

The preceding discussion of selected case histories helps to elaborate a sequence of emerging concepts or principles. I have already proposed seven:

1) The development of "transfer networks" of aquaculture species along which pathogens may move;

2) The reality that all introductions of aquatic pathogens have been to date accidental, even though introduction of host animals may have been intentional;

3) Restriction of in vivo experimental studies of fish pathogens to facilities within the zone where the organism is enzootic, unless fail-safe containment facilities exist elsewhere;

4) The need for early scientific attention to the appearance of a new parasite or pathogen;

5) The reality that disease risks from introductions are never zero;

6) The demonstration that once an introduced pathogen is established in a marine population it is difficult if not impossible to control its further spread; and

7) The observation that the colonization potential of many parasites in new environments is predictable.

Examination of additional cases of the relationship of diseases to importation of nonnative species discloses other generalizations:

1) Although evidence is less than robust and associations must often be made by deduction or inference, it is likely that many of the recent outbreaks of disease in marine populations of commercial importance—especially shellfish—are results of introductions of pathogens from other geographic areas. This may not be the case for salmonids, however, in which the most devastating outbreaks of disease are often due to agents already enzootic, and which are either amplified in aquaculture situations or which can infect an introduced species.

2) Introduced pathogens can be considered logically as "biological pollutants" and, as such, should be subject to all regulations governing pollutant discharge control. This perception of introduced agents has received some support, but has not yet, to my knowledge, been incorporated directly into regulatory regimes concerned with ocean pollution.

3) Disease-causing organisms may seem benign and innocuous in adapted host populations, but may become serious pathogens of related species when introduced into other geographic areas (for example, the eel nematode). Assessment of this potential risk can only be

Figure 4.— Nematodes, *Anguillicola crassus*, occluding swim bladder of European eel, *Anguilla anguilla*. Photograph courtesy of P. van Banning.

done in appropriately designed isolation wet-labs where imported and native stocks can be reared and studied together for some reasonable period of time (preferably one complete life cycle).

4) The possible role of infected resistant carriers in transmitting a disease to a susceptible but geographically separate subpopulation of the same species must be considered in decisions about transfers within the total geographic range of the species.

5) Two forms of disease risks exist when animals are relocated outside their normal range:

a) The infection of introduced stocks by an enzootic pathogen in the recipient country, to which native stocks are resistant—with the possible overwhelming of that resistance by increased infection pressure or increased virulence (Fig. 5).

b) The introduction of a pathogen that affects susceptible native species but to which the introduced stock is resistant (Fig. 6).

These dual risks may be further complicated by interbreeding of a resistant introduced stock with remnants of a disease-ravaged native stock.

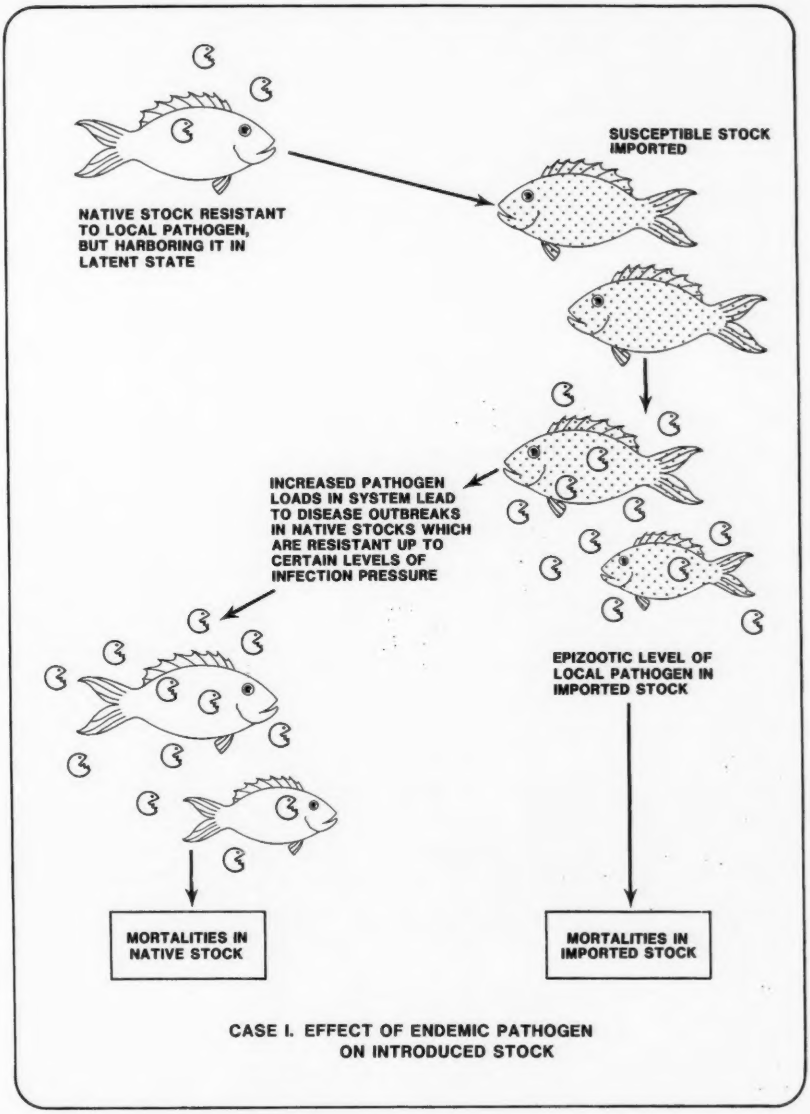

Figure 5. — Effect of an enzootic pathogen on an introduced stock.

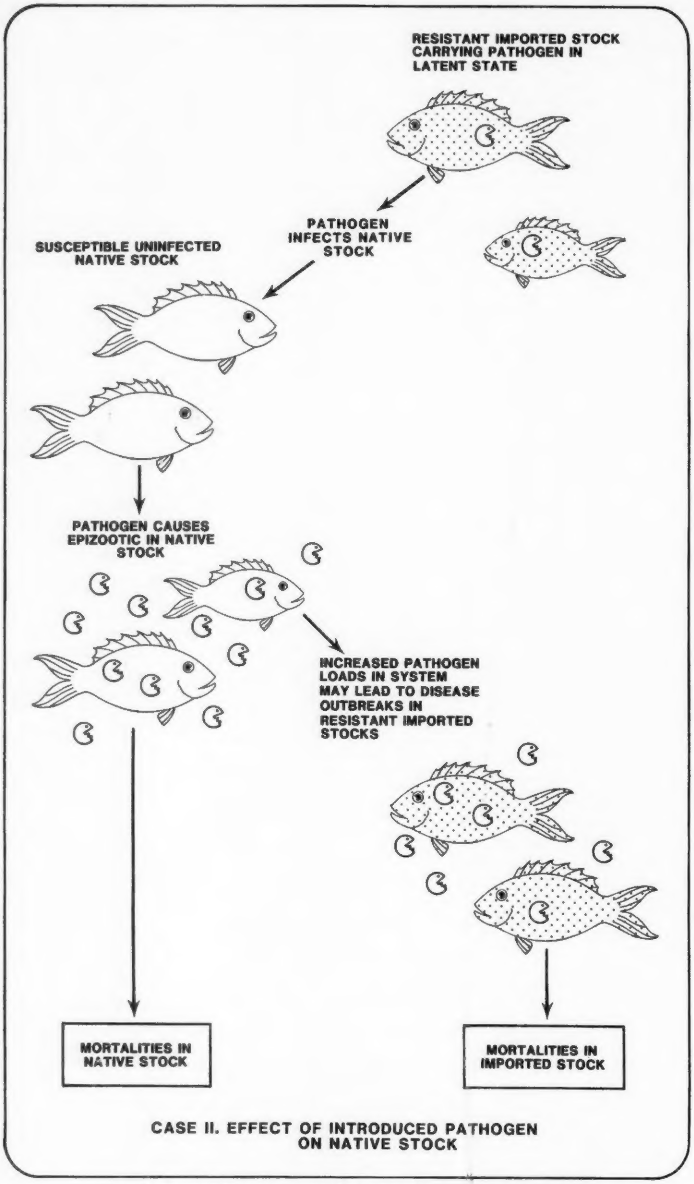

Figure 6. — Effect of an introduced pathogen on native stock.

This may lower the resistance of the new population to the pathogen. Another danger, particularly from introduced viral agents, is the rapid potentiation of virulence in intensive rearing facilities—as has been seen with IHNV in trout farms.

The validity of any of these proposed concepts or principles must, of course, be scrutinized continuously as new information becomes available. The listing here merely represents the author's assessment of our present understanding.

Recommendations

It is becoming increasingly apparent that national and international action is necessary to provide some measure of oversight and control of introductions of aquatic organisms, whether they be deliberate or accidental. Beyond this general recommendation, several proposed actions relate specifically to the problem of introduced diseases:

1) A substantial reduction in the global dissemination of diseases of aquatic organisms could be attained by the development of native species or species stocks, through scientific management and aquaculture practices (including selective breeding and genetic manipulation) as an alternative to introducing nonnative species.

2) A vigorous international program of marine disease research and control should be developed by the Permanent Commission for the Study of Fish Diseases of the International Office of Epizootics (OIE). This intergovernmental veterinary organization, based in Europe, is a logical focus for the kind of coordination that will be required (de Kinkelin et al., 1990). Included would be the development of models for inspection and certification programs, standardized protocols for disease examinations, and the implementation of an effective communication network.

3) Regional maps should be developed and kept current for each host species, showing the presence and abundance of each disease that affects the species. Movement of infected animals from an area where the disease is present to one where it is absent should be prohibited.

4) National and regional disease diagnostic centers, with supporting research capabilities, should be established to develop information about species proposed for introduction, or approved for introduction, or introduced accidentally.

5) Specific pathogen-free stocks of marine fish and shellfish should be identified for aquaculture purposes; these stocks should be used as sources of seed. A program should be developed that is modeled on one developed

principally by the U.S. Fish and Wildlife Service and already in use for salmonid hatcheries in the United States.

These recommendations relate specifically to disease problems; other and broader recommendations could and should be made concerning ecological, genetic, legal, and economic aspects of the importation of nonindigenous marine animals. Certain to be included would be these:

1) A clear national policy on introduced species, whether the introductions are accidental or deliberate, should be developed and stated.

2) A national system of inspection and quarantine, with adequate back-up research capabilities, should be developed and funded.

3) An effective regulatory regime and an enforcement system to ensure that regulations are not circumvented should be developed.

4) Proposed introductions should have clearly stated and demonstrated rational bases. Proposals which are without adequate rationale, poorly planned, or unnecessarily risky, should not be approved.

5) Decisionmakers should be aware of, and sensitive to, the practical, economic, social, and political aspects of introductions, but should evaluate proposals principally on the basis of the available scientific data. Relevant scientific implications and viewpoints include, but are not limited to:

a) Ecological considerations—including competition, predation, and community characteristics of species (diversity, carrying capacity);

b) Genetic considerations—including the potential for hybridization, change in gene frequency (genetic diversity), and change or modification in disease and/or parasite resistance;

c) Behavioral considerations—including interactions between native and exotic species; and

d) Pathological considerations—including the potential for unintentional introduction of diseases and parasites.

6) All proposed introductions should be accompanied by full and adequate procedures and provisions for post-importation (follow-up) monitoring.

Early consideration should also be given to acceptance, nationally and internationally, of a uniform code of practice concerned with movements of nonindigenous marine species. Consideration might also be given, in developing a U.S. policy on introduced aquatic species, to adopting the "precautionary principle" proposed by Germany and accepted at the Second International Conference on the Protection of the North Sea in 1987. That principle "requires action to reduce pollution even in the absence of soundly established scientific proof for cause and effect relationships." The principle could be applied especially to control accidental introductions (including pathogens), which are clearly forms of "biological pollution."

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The National Marine Fisheries Service Habitat Conservation Efforts in Louisiana, 1980 Through 1990

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Introduction

The Louisiana coastal zone includes about 1.5 million hectares of extremely valuable wetland habitat, approximately 41% of all remaining coastal wetlands in the United States. Louisiana waters contributed about 15% of the total U. S. fisheries harvest in volume in 1989, representing over $264 million in dockside value (NMFS, 1990). Dockside landings may generate at least three times this value as the product moves through processing stages and wholesale and retail markets within the state (Jones et al., 1974; Penn, 1974). Approximately 98% of the commercial harvest is comprised of estuarine-dependent fishery species (i.e., species that spend at least a part of their life cycle in coastal waters and wetlands). In addition, the annual contribution of licensed saltwater anglers to the state's economy has been conservatively estimated to exceed $600 million (Bertrand, 1984).

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ABSTRACT—Data quantifying various aspects of the Corps of Engineers wetland regulatory program in Louisiana from 1980 through 1990 are presented. The National Marine Fisheries Service (NMFS) habitat conservation efforts for this time period are described and averages involved delineated. From 1980 through 1990, NMFS reviewed 14,259 public notices to dredge, fill, or impound wetlands in Louisiana and provided recommendations to the Corps on 962 projects which proposed to impact over 600,000 acres of tidally influenced wetlands. NMFS recommended that impacts to about 279,000 acres be avoided and that more than 150,000 acres of compensatory mitigation be provided. During this period, marsh management projects proposed impounding over 197,000 acres of wetlands. On a permit by permit basis, 43% of NMFS recommendations were accepted, 34% were partially accepted, and 23% were rejected.

Louisiana coastal wetlands converted to open water at an average annual rate of 0.86 percent from 1955 to 1978. This amounted to an estimated loss of nearly 290,000 hectares of marsh for the entire 23 year period (Turner, 1990). Although Louisiana was losing about 130 km^2 of marsh per year in the mid 1980's to various land loss processes (Cowan et al., 1987), it appears as if this land loss rate may be slowing (Britsch and Kemp, 1990; Dunbar et al., 1990).

Wetland losses in Louisiana are caused by a variety of factors. In a comprehensive evaluation, Turner and Cahoon (1987) estimated that 26% of all wetland losses between 1955 and 1978 were directly attributable to some specific, identifiable coastal development activity. They attributed 56% of this direct wetland loss to canal dredging and the conversion of wetland to upland habitat by spoil placement. Most of the remaining direct causes of wetland loss were attributed to urban development and agricultural activities.

Indirect impacts are those wetland alterations resulting from direct impacts that occur at a different time or place. The wetland loss attributed to indirect impacts by Turner and Cahoon (1987) is primarily caused by saltwater intrusion, tidal scouring, subsidence, sea level rise, shoreline erosion, and sediment deprivation. Turner and Cahoon (1987) estimated 20–60% of all indirect wetland losses between 1955 and 1978 from identifiable causes were attributable to canal dredging and spoil bank construction, and 4–13% to outer continental shelf oil and gas activities (primarily pipeline construction).

Boesch and Turner (1984) emphasize that the key to management of estuarine-dependent species is coastal habitat protection and enhancement. Production of some estuarine-dependent fishery species has been shown to be proportional to the area of nearby wetlands (Turner, 1977), or to the length of the land-water interface (Browder et al., 1989). Because the National Marine Fisheries Service (NMFS) is the Federal agency responsible for the management of our Nation's living marine resources, the conservation of habitat supporting these resources is of prime importance to the agency. Within the NMFS, this responsibility is fulfilled by the Habitat Conservation Division (HCD).

The U.S. Army Corps of Engineers (Corps) is responsible for the Federal permitting of dredge and fill activities in wetlands under Section 404 of the Clean Water Act. They also regulate alteration of navigable waters under Section 10 of the Rivers and Harbors Act. Each year thousands of requests are made to the New Orleans District Corps of Engineers for Section 10 or 404 permits pertaining to wetland development in southern Louisiana. Once an application pertaining to Section 10 or 404 activities is received, the Corps may issue a public notice describing the proposed activities and geographic location of the project area. Because wetland alterations can adversely impact marine fishery resources, the HCD provides recommendations to the Corps concerning pro-

posed activities. These recommendations are designed to avoid, minimize, or offset adverse project effects on marine, estuarine, and anadromous fishery resources and their habitats.

Since May 1980, the HCD has maintained a database for public notices issued by the Corps for Section 10 and 404 activities and our responses to those wetland alteration proposals. This report summarizes data from May 1980 through December 1990 on public notices and permits issued by the Corps for Section 10 and/or 404 activities in Louisiana, HCD recommendations concerning those proposed activities, and Corps actions on HCD recommendations.

Methods

A computerized system to track HCD permit recommendations and proposed habitat alterations in the southeast was instituted in 1980 and was preliminarily reported on by Lindall and Thayer (1982) and summarized for 5 years by Mager and Thayer (1986). Since 1985, annual publications have been prepared to report and discuss coastal development activities in the southeast (Mager and Keppner, 1987; Mager and Hardy, 1988; Mager and Ruebsamen, 1988; Mager, 1990a,b).

Data entered into the system were acquired directly from public notices and field investigations by HCD staff and contractors. These data were entered into one of two primary databases pertinent to Corps public notices. The largest database contains administrative information and tracks variables obtained from each public notice. Variables in this database describe the geographic location of, type of activity applied for (Table 1), and HCD response to the proposed activity.

The second database contains data pertinent to only those public notices for which the HCD recommended project alterations or permit denial. This database contains variables which, in general, describe the area (acres) of all habitats proposed by the applicant to be altered, the HCD recommendations in regard to proposed habitat alterations, and the Corps' response to HCD recommendations as contained in issued permits and statements of finding.

Table 1.—National Marine Fisheries Service, Habitat Conservation Division, activity type codes and descriptions.

Code	Description
BA	Barriers and impoundments (e.g., dams, dikes, fences, flood control structures, levees, weirs)
BE	Beach restoration
BR	Bridges and highways
DO[1]	Docks, dolphins, piers, wharves, mooring piles
EL	Electrical generating plants
HO	Housing developments (including residential modifications, house pads, septic tanks)
IN	Industrial or commercial development
IR	Irrigation, drainage, or mosquito control
MD[2]	Maintenance dredging
MI	Mining and mineral dredging (e.g., commercial sand dredging)
MM	Marsh management
NA	Navigation channels and marinas
OI	Oil and gas activities
OT	Other (not described by other codes)
PI	Pipelines
SH	Shoreline activities (e.g., bulkheads, groins, jetties, ramps, rip-rap)
TR	Transmission lines (e.g., telephone cables)
WR[3]	Wetlands restoration

[1]Prior to 1986 identified as SH.
[2]Prior to 1986 identified as NA.
[3]Not used prior to 1990.

Data from both files were merged for those public notices for which the HCD recommended permit denial or project revision. This combined data set was used to determine acreages of each habitat type for which the HCD made recommendations, the percentage of HCD recommendations accepted by the Corps for each activity type and year, the area of each habitat type conserved by HCD recommendations, and the acreage of all habitats in the HCD database permitted by the Corps for alteration.

Results and Discussion

Total Public Notices

Over 11,500 public notices for wetland alteration activities in southern Louisiana were received by the HCD between May 1980 and 31 December 1990 (Table 2). Most (8,170 or 71%) described activities requiring permits under both Section 10 of the Rivers and Harbors Act and Section 404 of the Clean Water Act. Alterations to navigable waters (Section 10 activities) were proposed in 25%, and dredged material disposal and fill activities requiring only Section 404 review were identified in about 3% of all public notices.

Oil and gas activities were the most numerous project types identified in public notices during this period, followed by shoreline activities and pipelines (Table 3). When the number of public notices for oil and gas are combined with those for pipelines, at least 52 percent of all Section 10/404 public notices issued by the Corps involved petroleum exploration and production activities. In addition, an unquantified number of public notices in the barriers and impoundments, docks, maintenance dredging, navigation channels, and shoreline activities project type categories described activities related to petroleum development. Several thousand minor oil and gas activities requiring Section 10/404 review, autho-

Table 2.—Number of public notices issued for each kind of activity and the number of permit NOD-22's issued from May 1980 through December 1990, by year.

	Public notice					
Year	Sect. 10	Sect. 404	Sect. 10/404	Total	NOD-22	Total
1980	NA[1]	NA	1,035	1,035	NA	1,035
1981	NA	NA	1,611	1,611	NA	1,611
1982	678	25	942	1,645	NA	1,645
1983	484	22	783	1,289	52[2]	1,341
1984	338	13	735	1,086	431	1,517
1985	323	19	666	1,008	598	1,606
1986	272	40	534	846	292	1,138
1987	201	19	594	814	324	1,138
1988	174	44	450	668	376	974
1989	174	59	485	718	358	983
1990	234	141	415	790	486	1,271
Total	2,878	382	8,250	11,510	2,917	14,259

[1]N/A = Data not available.
[2]26 September–31 December, 1983 only.

Table 3.—Number of New Orleans District Corps of Engineers public notices issued from May 1980 through December 1990, by project type, and the number and percent of the total (in parenthesis) of each project type involved in NMFS habitat conservation recommendations.

Project type[1]	Number of public notices	Number of recommended revisions
BA	365	76 (21)
BE	4	1 (25)
BR	115	9 (8)
DO	318	0 (0)
EL	5	0 (0)
HO	139	34 (24)
IN	290	40 (14)
IR	125	12 (10)
MD	272	61 (22)
MI	104	15 (14)
MM	131	91 (69)
NA	587	122 (21)
OI	4,678	697 (15)
OT	228	28 (12)
PI	1,360	73 (5)
SH	2,622	106 (4)
TR	131	1 (1)
WR	3	1 (33)
N/A[2]	33	14 (45)
Total	11,510	1,381 (12)

[1]See Table 1 for code descriptions.
[2]Project type not identified.

rized under general permits and areawide maintenance dredging permits are not included in these figures.

Oil and gas exploration and production was the most frequent project type for all years combined, and for each year from 1980 through 1988. However, in 1989 and 1990, shoreline activities such as bulkheads, riprap, and jetties became the most common project type advertised in public notices. Oil and gas activities and barrier/impoundment construction were the second and third most common project types in 1989 and 1990. Decreases in oil and gas, shoreline activities, pipeline, and navigation project types are one primary reason for the overall annual decrease in public notices issued between 1982 and 1988 (Table 2). Much of the decrease in public notice numbers also can be attributed to the establishment of general permits.

General Permits

General permits authorize Section 10/404 activities that are similar and cause minimal individual environmental impacts. During our study period, the Corps issued permits in 16 general permit categories. These general permits cover a wide range of activities and the number of general permits issued yearly varies widely among categories. The Corps normally notifies only the NMFS, U.S. Fish and Wildlife Service (FWS), and U.S. Environmental Protection Agency (EPA) of activities proposed for authorization, or already authorized under a general permit.

General permit NOD-22, established in 1983, authorizes "minor" activities in the Louisiana coastal zone, is the most frequently used of 16 general permits, and is the only general permit for which resource agencies have comment authority. The NOD-22 authorized several hundred Section 10/404 projects annually during the study period (Table 2). If the agencies believe the anticipated impacts of a project are greater than allowed for under NOD-22 special conditions, they may request the project be advertised under standard public review procedures.

The majority of NOD-22 permits pertain to oil and gas activities. NOD-22 permits, along with several other general permits and numerous areawide maintenance dredging permits have greatly reduced the number of individual public notices issued for oil and gas activities. Total general permit authorization in 1985, 1989, and 1990, the only years for which data are available, totalled 852, 657, and 824 respectively. Therefore, general permit authorizations in Louisiana were issued almost as frequently as public notices in 1985 and 1989 and were more numerous in 1990.

Area-wide maintenance dredging permits, first authorized in 1987, allow maintenance of existing canals within a developed oil and gas field, with Federal agency review only. The NMFS, FWS, and EPA are notified by the Corps for each specific maintenance dredging application and are allowed a 20-day comment period. This type of permit has reduced the number of public notices issued for the 1987 through 1990 period. For example, approximately 200 general permits for specific maintenance dredging events (called maintenance dredging determinations) were issued in 1989 alone. The few recommendations made by the resource agencies in response to maintenance dredging determinations were related to using dredged material to nourish subsiding wetlands, or to create soil elevations conducive to the establishment of marsh vegetation in eroded shallow water areas. Because of the already impacted nature of the areas, the brief review period, and the large number of such applications, HCD recommendations on NOD-22 and maintenance dredging determinations generally were based solely on the review of readily available resource information (primarily aerial photographs).

NMFS Recommended Revisions

During the study period, the HCD recommended plan revisions or permit denial for 1,380 or 12% of all proposed Section 10/404 projects advertised in Corps' public notices (Table 3). The annual percent of public notices for which the HCD provided substantive comments changed little, varying from a low of 10% in 1983, 1984, 1986, and 1990, to a high of 15% in 1985 and 1988. The HCD, therefore, did not object to, or did not provide substantive comments on, the majority of public notices issued each year. This was primarily because: 1) Projects were minor and expected to have little or no adverse impacts on marine fishery resources or 2) projects were in areas not supportive of marine fishery resources, such as nontidal wetlands, leveed fastlands, or previously impounded areas.

The HCD categorizes recommendations made on a project into three different levels: 1) Denial with no alternatives recommended, 2) permit denial unless less damaging alternatives are incorporated into the project, and 3) permit requires relatively minor revisions. Only 3% of all projects receiving substantive comments were recommended for denial without alternative designs. Projects in this category are usually not water-dependent or do not appear to be in the public interest, and no alternative designs or locations are feasible which would minimize adverse impacts to fishery resources while allowing the applicant to achieve the project objectives.

The HCD recommended project revisions in 97% of the substantive comments provided to the Corps. The HCD recommended revision of certain project categories because they are not water-dependent, less damaging alternatives were available, or mitigation to offset impacts was necessary. Housing and industrial development are project types where the HCD often recommends project denial or requests revision. The cumulative effects of many, generally small, projects on wetland habitats can be extremely large, especially when large housing concentrations are used to justify flood protection in the form of levees and forced drainage projects. Direct loss of wetlands caused by levee construction and indirect impacts caused by the release of untreated sewage from camps, runoff from housing and industrial development projects, and industrial discharge degrade aquatic habitats and fishery productivity. HCD comments for housing/industrial projects generally

involve recommending the project be relocated to a non-wetland area, that the project be revised to minimize and offset wetland impacts, or that the project incorporate measures to reduce the potential for water pollution from the site.

Although the proportion of oil and gas projects for which the HCD recommended revisions is relatively small (15%), the large number of public notices issued for this activity makes it the project type on which NMFS most frequently commented (Table 3). Of all the projects for which the HCD has recommended revision or denial, 56% (770 of 1,380) concern petroleum exploration and production activities (oil and gas activities and pipelines). The HCD most frequently recommends minimization of the length of well access canals and roads or relocation of ring levee sites to nonwetland areas. Our review often includes a geologic review process (described in Johnson et al., 1989) to determine alternative surface locations from which the desired geological target could be reached. After determining the area from which a well could be drilled, the least environmentally damaging access route to the well site is recommended based on review of aerial photographs and other resource information. In addition, the HCD often recommended: 1) The use of a containerized system when drilling fluids or cuttings associated with drilling fluids contain oil base fluids, heavy metal additives, asbestos viscosifiers, corrosion inhibitors, chlorinated phenol biocides, or any other substances classified as priority pollutants by the EPA; and 2) all produced waters from production operations be held in closed storage containers until they can be reinjected or be transported to and disposed of at a state approved upland site. The HCD also seeks compensatory mitigation for lost or degraded wetlands for projects where adverse impacts cannot be avoided.

When the HCD provided recommendations on pipeline activities, it was usually to request that the pipeline be routed to follow spoil-bank contours, the pipeline be laid on the marsh without burial, the pipeline right-of-way be restored, or that pipeline/waterway intersections be armored with riprap to prevent erosion. The few shoreline activities the HCD commented on generally involved construction of a bulkhead along a waterway and filling of wetlands behind the bulkhead. In these cases, the HCD generally recommended the bulkhead be constructed at, or landward of, the mean high water line and that project area wetlands not be filled or dredged.

Marsh Management

The HCD recommended revisions to 69% of all marsh management projects advertised in public notices (Table 3). Although the HCD often objected to and recommended revision of marsh management projects, the frequency of objections fluctuated a great deal annually. For example, the HCD recommended revision to 45% of marsh management projects in 1982 but objected to issuance, without project revisions, to 100% of all marsh management projects in 1988.

Marsh management projects normally employ water control structures and levees to hydrologically isolate marshes from adjacent water-bodies and to manipulate water flows and levels to achieve some expected benefit. Such projects generally have a goal of reducing land loss or saltwater intrusion, or increasing wildlife harvest from managed areas (Cahoon and Groat, 1990). Although marsh management can concentrate waterfowl, especially by retaining water during winter low water periods, there is no scientific documentation that it reduces land loss or controls saltwater intrusion. To the contrary, recent research in Louisiana (Cahoon and Groat, 1990; Reed and McKee, 1991) reported decreased sediment and nutrient import, reduced vertical accretion, and in the deltaic plain, decreased plant health, in managed as compared to unmanaged marsh systems. Cahoon and Groat (1990) and research reported in Herke (1968, 1979), Herke et al. (1987a;b), Herke et al. (1992), Konikoff and Hoese (1989), and Pittman and Piehler (1989) have shown significantly reduced standing crops and production of commercially and recreationally important marine fishery resources as a result of marsh management practices. Considering the total wetland acreage proposed for marsh management (over 200,000 acres); the approximately 400,000 acres proposed in the state of Louisiana's 1990–92 coastal restoration plans; the thousands of acres already under management; and the impact of water control structures and dams on fishery migrations, it is evident that marsh management may have significant adverse impacts on the production of a vast commercially and recreationally important marine fishery resource base in Louisiana.

HCD responses to marsh management projects in the early 1980's were influenced by the paucity of scientific knowledge that existed on the impacts of marsh management. During the 1980–85 period, the HCD recommended revisions to an average 54% of all marsh management projects. This rose to 78% for the 1986–90 period. It was during the latter period that most studies detailing the significant adverse impacts of water control structures on fisheries production were published. As this new information became available, the HCD approach toward permitting marsh management projects became more conservative.

Based on site-specific conditions, HCD recommendations related to marsh management and barrier/impoundment projects varied considerably among projects. The HCD did not recommend permit denial for those projects proposing to maintain already impounded areas or that had both a well documented need and public benefit, and which minimized adverse impacts to marine fishery resources. However, many projects have been proposed that would impound wetlands without adequate justification, or manage marshes for a single resource at the expense of marine fisheries production. For these projects, the HCD recommended project revisions or permit denial.

When a management plan could be implemented without significantly impacting marine fishery resources and wetland processes (e.g., in nontidal and some freshwater, tidal wetlands), we usually recommended monitoring of

various environmental parameters to determine the effectiveness and need for modification of the marsh management plan. In coastal wetlands that support marine fishery resources, we often recommended project design alterations or changing the timing of structural operation to allow greater access by fish and shellfish or nutrient/sediment exchange. In addition, since 1986, we have routinely recommended that, prior to authorization of new plans, an environmental impact statement be prepared to assess cumulative and long-term impacts of marsh management on Louisiana's coastal resources. While more than 600,000 acres are proposed for or under management in Louisiana's coastal zone, an environmental impact statement to evaluate impacts and alternatives has not been prepared. This demonstrates the immediate need for a comprehensive environmental document that examines all aspects of marsh management in Louisiana.

Acreage Data

The NMFS acreage database contains information from only those public notices for which the HCD recommended permit denial or project revision. The database therefore contains acreage data for 10–15% of the public notices issued annually by the New Orleans District Corps of Engineers.

Acreage data were recorded on 962 public notices during the 1980–90 period (Table 4). During this period, the HCD recommended conservation of 44% (4,738 of 10,704 acres) of those acres proposed for dredging by permit applicants. The greatest amount of acreage proposed for dredging and included in HCD conservation efforts was recorded during the 1980–85 period. Since 1985, only 35% of the total dredging acreage was proposed. The decrease in proposed dredging since 1985 probably reflects a downturn in the state's economy, increased utilization of general permits, and a greater use of directional drilling techniques for petroleum exploration.

The HCD opposed filling 27,798 acres of Louisiana's coastal wetlands and waterbodies between 1980 and 1990, which represents 81% of the fill acreage proposed by applicants. Of the acreage proposed for filling and included in HCD detailed recommendations, 55% is from one 1985 public notice—a proposed ship channel across Vermilion Bay to the Port of Iberia which entailed dredging and filling 1,045 and 18,770 acres, respectively. The HCD recommended the permit for the proposed ship channel not be issued, and the Corps, in denying the permit, concurred. Excluding that project, the HCD recommended conservation of 59% of the total proposed fill acreage.

The impound category contains the largest total acreage values in the database. Over 560,000 acres of marsh were proposed for impounding via levees and/or water control structures during the 1980–90 time period. Projects having acreage in this category include forced and gravity drainage flood control projects, hurricane protection levees, and marsh management projects. These projects range in scope from areas where several water control structures and miles of levees completely control the hydrology of thousands of acres to those projects containing one small structure which affects the hydrology of only a few acres.

HCD recommended that over 157,000 acres of Louisiana coastal wetlands be mitigated to offset adverse fishery impacts (Table 4). This mitigation figure reflects only those wetland compensation acreages requested for creation, restoration, or enhancement after project impacts had been minimized to the extent practicable. During the 1980–90 period, most of the mitigation recommended by NMFS involved habitat enhancement or preservation rather than creation. Relatively few recommendations were made during this period to require applicants to replace what was altered; most efforts were made to restore, preserve, or enhance wetlands through canal plugging, water management, or constructing erosion control structures.

Mitigation for wetland alterations varied among project types. For oil and

Table 4.—Number of proposed projects in Louisiana, and acreage, subject to NMFS habitat conservation recommendations for each year from May 1980 through December 1990.

	Proposed projects and acreage											
	1980[1]	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	Total
Number of public notices	3	135	160	113	97	107	65	69	76	70	67	962
Acreage proposed by applicant												
Dredge	10	1,022	950	744	1,198	2,997	575	394	444	999	1,371	10,704
Fill	26	1,847	2,282	1,269	2,929	20,352	1,043	448	394	2,942	635	34,167
Impound	0	2,717	12,219	35,914	47,086	23,806	52,808	10,971	340,860	17,409	16,879	560,669
Acreage accepted by NMFS												
Dredge	4	640	662	418	971	1,754	237	177	258	402	443	5,966
Fill	16	977	1,269	630	635	846	283	127	156	1,143	287	6,369
Impound	0	2,200	3,219	32,213	41,975	804	51,481	4,737	168,800	5,464	3,400	314,293
Mitigate	16	1,039	2,650	28,567	41,944	14,673	48,725	6,250	338	6,777	6,782	157,761
Potential acreage conserved												
Dredge	6	382	288	326	227	1,243	338	217	186	597	928	4,738
Fill	10	870	1,013	639	2,294	19,506	760	321	238	1,799	348	27,798
Impound	0	517	9,000	3,701	5,111	23,002	1,327	6,234	172,060	11,945	13,479	246,376
Mitigate	16	1,039	2,650	28,567	41,944	14,673	48,725	6,250	338	6,777	6,782	157,761

[1]Records for 1980 are incomplete.

gas activities, the HCD often recommended restoring a canal or ring levee upon abandonment. Restoration might include plugging and backfilling oil and gas canals, placing gaps or openings in spoil banks, tearing down ring levees and returning the material to borrow pits, or using dredged material to create or restore wetlands in open water areas (Moore et al., 1985). Typically, for marsh management or barrier project types, the HCD recommended methods to maintain or increase fishery access to impounded wetlands and then recorded mitigation acreage equal to that impounded.

When we look at Section 10/404 activities by hydrologic basins, four of the seventeen basins account for approximately 50% of all public notices issued (Table 5). More Section 10/404 activities were proposed for Barataria Basin than any other. This is due primarily to a combination of the relatively large wetland acreage of the basin, the large number of oil and gas fields found there, and the large population base in the vicinity of the basin. While the Barataria Basin was only third in number of oil and gas activities (Atchafalaya Bay and Gulf of Mexico were first and second, respectively), more public notices for shoreline, navigation, dock, maintenance dredging, and marsh management projects were advertised for the Barataria Basin than any other, and it was among the top two basins in frequency of the remaining project types.

The Vermilion Bay drainage basin contained the largest area proposed for dredging and filling for the 1980–90 period in Louisiana (Table 5). Of the acreage in Vermilion Bay, 54% proposed for dredging and 95 percent proposed for filling were attributable to one public notice for a ship channel across Vermilion Bay. Barataria Bay and the Mississippi Delta contain the second and third largest proposed dredge acreage, respectively.

After Vermilion Bay, the basins having the most acreage proposed for filling in decreasing order, are Terrebonne Bay, Barataria Bay, and the Mississippi Delta (Table 5). Twenty-three percent of the acreage proposed for impounding is not identified with a specific basin. This comes from four public notices for repair and maintenance of several hundred fixed-crest weirs and plugs in the Barataria, Caillou, and Terrebonne Bay basins. Because these public notices included water control structures in more than one basin, it was placed in the "not identified" basin category. Excluding this category, Barataria Bay, Terrebonne Bay, and the Lake Pontchartrain basins, in decreasing order, have the greatest acreage proposed for impoundment.

Table 5.—Total number of New Orleans District Corps of Engineers public notices and the number of public notices and associated acreage subject to NMFS habitat conservation recommendations (Code I notices) for activities proposed in each drainage basin from May 1980 through December 1990.

Drainage basin	Total public notices	Number commented on	Code I public notices: Acreage proposed by applicant: Dredge	Fill	Impound
Atchafalaya Bay	1,617	51	337	674	4,460
Barataria Bay	1,812	245	1,567	2,526	200,775
Breton Sound	523	48	573	1,059	8,700
Caillou Bay	250	30	270	396	27,150
Calcasieu Lake	407	46	378	345	23,674
Chandeleur Sound	188	6	12	92	0
Grand Lake	707	96	492	802	11,701
Gulf of Mexico	1,048	17	909	426	0
Lake Borgne	100	29	93	213	10,142
Lake Pontchartrain	789	55	302	853	32,380
Mississippi Delta	287	36	1,466	2,083	0
Mississippi River	588	7	529	33	0
Terrebonne Bay	1,206	174	1,090	4,556	83,150
Timbalier Bay	119	11	61	63	1,150
Vermilion Bay	666	93	2,383	19,760	17,225
White Lake	102	16	190	254	10,759
Not identified[1]	1,101	2	49	33	129,400
Total	11,510	962	10,701	34,168	560,666

[1]Most public notices in this category described projects located far inland from the coastal basins; a few projects impacted more than one basin.

The habitat proposed most frequently for alteration is mud. This classification was utilized for 991 public notices and includes unvegetated mud waterbottoms, intertidal flats, and those areas of mixed or unknown sediment composition. Other habitats frequently involved in HCD conservation efforts and the number of projects impacting each habitat (in parenthesis) are *Spartina patens* marsh (544), freshwater marsh (314), "other" marsh (289), *Spartina alterniflora* marsh (242), hardwood swamp (121), and *Distichlis spicata* marsh (100).

The project type having the most proposed dredge and fill acreage in the NMFS database is the navigation channels and marinas category (Table 6). Thirty percent of the dredging acreage and 87 percent of the fill acreage in the navigation channels category are from the proposed channel across Vermilion Bay.

HCD acceptance of project impacts varied with project type (Table 6). Dredge and fill acreage for bridges/highways, irrigation, and pipeline projects had the highest HCD acceptance rate while housing, commercial development, shoreline activities, and navigation project types had relatively low acceptance rates. The reasons for the relatively low acceptance of wetland dredge and fill acreage proposed for those project types have been discussed previously, and include the lack of water dependency, poor project designs, impacts to NMFS trust resources, availability of less damaging alternatives, and poor suitability of wetlands for the purposes of projects in those categories.

Of the impound acreage, 63% is for projects in the barrier and impoundment category and 35% is for marsh management projects (Table 6). Most of the impound acreage (90%) in the barrier project type category is for the four public notices by a single landowner proposing the replacement, repair, or maintenance of hundreds of weirs and plugs. The remaining 45 barrier/impoundment projects impacted 36,633 acres. The 61 marsh manage-

Table 6.—Applicant proposed and NMFS recommended acreages by project type for coastal Louisiana from May 1980 through December 1990. (Numbers in parenthesis represent the proportion of the area recommended to the area proposed.)

Project type[1]	No. of public notices	Acreage: Proposed by applicant: Dredge	Fill	Impound	Recommended by NMFS: Dredge		Fill		Impound		Mitigate
BA	48	2,318	799	353,538	941	(41)	549	(69)	174,630	(49)	7,281
BE	1	134	0	0	0	(0)	0		0		0
BR	3	40	8	0	32	(80)	0	(0)	0		47
HO	32	129	578	20	36	(28)	205	(35)	0	(0)	0
IN	34	206	529	106	63	(31)	7	(1)	0	(0)	41
IR	9	101	95	4,460	69	(69)	82	(86)	0	(0)	162
MD	37	505	2,727	0	407	(80)	917	(34)	0		888
MI	5	140	0	0	0	(0)	0		0		0
MM	61	425	306	197,131	284	(67)	199	(65)	139,664	(71)	139,558
NA	74	3,223	21,526	739	1,756	(54)	573	(3)	0	(0)	1,838
OI	531	3,133	6,485	927	2,108	(67)	3,428	(53)	0	(0)	4,364
OT	17	136	615	744	106	(78)	142	(23)	0	(0)	178
PI	47	160	327	0	136	(85)	220	(67)	0		221
SH	58	35	70	4	11	(31)	11	(16)	0	(0)	179
WR	1	7	7	3,000	7	(100)	7	(100)	0	(0)	3,000
Not ID[2]	4	10	95	0	10	(100)	28	(29)	0		2
Total	962	10,702	34,167	560,669	5,966	(56)	6,368	(19)	314,294	(56)	157,759

[1]See Table 1 for code descriptions.
[2]Not identified.

ment projects proposed the impoundment of almost 200,000 acres, an average of 3,232 acres for each management area.

The HCD did not object to proposals affecting 56% of the total area to be impounded. Although the HCD did not recommend permit denial for much of the proposed impoundment area, structural and management alteration recommendations often were made to maximize marine fishery access to impounded marshes. These measures are reflected as mitigation for the barrier and marsh management project types. The HCD did recommend against permit issuance for all of the acreage proposed for impoundments associated with housing development, irrigation and drainage, navigation, oil and gas activities, and "other" project types (Table 6). This is because impounding wetlands is usually unnecessary and avoidable for many of these types of projects.

Corps Final Action

The NMFS did not begin determining the Corps' final action on HCD recommendations until 1982. Once begun, the HCD recorded the dredge, fill, and impound acreage authorized, and determined whether the Corps had accepted, partially accepted, or rejected HCD recommendations by comparing the issued permit with the public notice and HCD letters of recommendation.

The Baton Rouge HCD office has permits for 544 of the 962 public notices (57%) for which the HCD provided recommendations to the Corps to reduce habitat loss and alteration (Table 7). An additional 162 applications advertised through public notices and proposing to dredge, fill, and impound 23,752 acres were withdrawn due, at least in part, to HCD objections. About 250 public notices in the NMFS habitat conservation database have no final action recorded. Of this amount, 138 are from 1980 and 1981 when the NMFS did not determine Corps acceptance of HCD recommendations. The majority of the remaining public notices await final Corps action.

A comparison of the acreage proposed for alteration by applicants and permitted by the Corps, for permitted projects only, reveals that 79% of the dredging acreage, 21% of the proposed fill acreage, and 96% of the proposed impound acreage involved in HCD habitat conservation efforts was permitted by the Corps (Table 7). Approximately 1,200 acres were protected from dredging, 20,200 from filling (18,880 of which can be attributed to the Corps' denial of the proposed ship channel across Vermilion Bay), and 18,700 acres were preserved from impounding. Combining the

Table 7.—Number of permits issued, acres permitted, and acres conserved and withdrawn, involved in NMFS habitat conservation recommendations for Louisiana from 1982 through 1990, by year.[1]

	Permits, applications, and acreage by year[1]: 1982	1983	1984	1985	1986	1987	1988	1989	1990	Total
Number of permits issued	81	103	64	72	43	50	48	54	29	544
Number of applications withdrawn	14	32	19	31	12	21	16	10	7	162
Acreage proposed by applicant										
Dredge	431	513	433	1,296	439	200	214	1,589	484	5,599
Fill	1,159	1,018	663	1,375	736	249	231	19,104	853	25,388
Impound	3,190	13,999	52,801	23,724	3,450	7,151	17,209	340,875	18,839	481,238
Acreage recommended by NMFS										
Dredge	307	381	297	1,159	273	84	157	292	252	3,202
Fill	722	583	389	947	158	114	116	128	309	3,466
Impound	2,677	9,214	47,191	16,166	1,765	6,794	16,184	176,000	4,991	280,982
Mitigate	1,011	10,301	41,474	19,329	13,278	6,877	12,872	8,235	4,911	118,288
Acreage permitted by Corps										
Dredge	410	496	378	1,272	402	175	193	769	320	4,415
Fill	1,066	917	584	1,090	523	164	209	219	401	5,173
Impound	3,001	7,405	52,766	23,321	2,201	6,964	12,464	340,194	14,206	462,522
Mitigate	946	4,316	45,868	26,025	12,992	6,923	7,950	8,098	4,424	117,542
Acreage conserved										
Dredge	21	17	55	24	37	25	21	820	164	1,184
Fill	93	101	79	285	213	85	22	18,885	452	20,215
Impound	189	6,594	35	403	1,249	187	4,745	681	4,633	18,716
Acreage withdrawn by applicant										
Dredge	107	178	203	727	90	205	601	75	39	2,225
Fill	359	405	296	391	119	230	1,366	96	2,363	5,625
Impound	0	101	0	1,897	760	6,430	252	6,920	302	16,662

[1]Year permit issued or application withdrawn.

acreage conserved with that withdrawn shows that about 3,400 wetland acres were not dredged, 35,840 were not filled, and 34,600 were not impounded due, at least in part, to NMFS recommendations.

Further comparison of acreage recommended by the HCD with that permitted by the Corps (Table 7) reveals that the Corps did not accept HCD recommendations to avoid impacts associated with 1,213 acres of dredging, 1,707 acres of filling, and 18,540 acres of impoundment. In addition, the HCD recommended 741 acres of mitigation more than the 117,542 acres required by the Corps.

Seventy percent of the wetland acreage proposed for dredging, filling, and impounding for marsh management during the 1980–90 period, and in the NMFS database, had been permitted by the Corps by the end of 1990 (Table 8). HCD has been notified of an additional 11,462 acres (6%) proposed for marsh management which were withdrawn by the applicant. Much of the area permitted for marsh management is located, in decreasing order, in the Barataria Bay, Terrebonne Bay, Calcasieu Lake, and Vermilion Bay basins (Table 8). The Barataria Bay basin has the greatest number of marsh management projects (14), followed by Grand Lake and Vermilion Bay with 10 each.

As of 31 December 1990, the HCD had not been notified of final action (permit issuance or denial, application withdrawn or returned) on almost 44,000 acres that have been proposed for marsh management in Louisiana (Table 8). Most of the marsh management acreage pending Corps action entails the impoundment of waterbottoms (mud habitat), *S. patens* marsh, and freshwater marsh.

It should be noted that the HCD database contains only those marsh management projects for which public notices were issued between 1980 and 1990, and for which the HCD recommended modifications. It does not contain the 100,000+ acre Cameron-Creole marsh management project which was proposed prior to 1980 and implemented in 1988, the 123,000 acre Lafourche Parish plan proposed in February 1991, the thousands of acres managed on state and Federal wildlife refuges, or the hundreds of thousands of acres impounded and placed under management prior to implementation of wetland regulatory legislation and guidelines. Many of these "grandfathered" marsh management projects are located in the Grand, White, and Calcasieu Lake drainage basins of the Chenier plain and the Terrebonne and Caillou Bay basins of the deltaic plain. The habitats most impounded in those management areas are *S. alterniflora* and *S. patens* marshes which are managed to control human access and enhance wildlife harvest.

Most of the acreage conserved from impacts associated with dredging and filling was unvegetated mud bottom habitat (resulting primarily from Corps denial of the ship channel in Vermilion Bay). Other habitats having significant acreages preserved include *S. patens* marshes, hardwood swamps, *Ruppia* sp. vegetated waterbottoms, and "other" marsh (Table 9).

In some cases, a larger acreage of dredging or filling was permitted than was proposed by an applicant. This generally occurred when a natural resource agency recommended altering a project to conserve what was judged to be an important habitat (such as freshwater or *S. patens* marsh) at the expense of a less important habitat (such as mud or sand waterbottoms). Moving the project site may have resulted in a larger area being impacted, but if the new project site was determined to have a much lower habitat value, such recommendations are justified.

The term "withdrawn" is somewhat misleading in that it includes projects withdrawn by the applicant and those returned to the applicant by the Corps because of lack of response to their request for additional information or clarification. While the NMFS cannot claim credit for all 125,000 acres conserved from dredging, filling, and impounding by permit withdrawal (Table 10), comments made by the HCD to the Corps caused the Corps to delay permitting and request more detailed information from applicants on some projects. Although most of the acreage conserved was unconsolidated mud waterbottoms (Table 10), large acreages of sand, freshwater marsh, and *S. patens* marsh were also protected. Approximately half of the acreage conserved from impounding by withdrawal

Table 8.—Acreage of marsh management plans applied for, permitted, and pending in coastal Louisiana between May 1980 and December 1990, by drainage basin.

Drainage basin	No. of public notices	Acreage proposed by applicant[1]			Number of permits	Acreage permitted by Corps[2]				Acreage pending		
		Dredge	Fill	Impound		Dredge	Fill	Impound	Mitigate	Dredge	Fill	Impound
Atchafalaya Bay	3	24	8	4,460	2	15	4	800	1,200	9	4	3,160
Barataria Bay	14	84	80	63,670	10	51	65	56,295	45,515	3	5	1,970
Breton Sound	3	45	27	8,700	1	14	3	2,660	0	18	5	2,960
Caillou Bay	4	42	97	32,087	3	17	9	11,677	7,222	25	88	20,410
Calcasieu Lake	6	30	16	19,024	5	26	15	7,700	13,420	4	1	7,224
Grand Lake	10	39	39	9,814	5	15	11	4,604	4,702	6	6	2,050
Lake Borgne	4	26	23	12,858	3	23	23	7,988	4,825	3	0	2,762
Lake Pontchartrain	2	2	2	12,760	1	1	1	12,460	7,858	0	0	0
Terrebonne Bay	6	23	30	18,043	5	48	65	16,796	16,798	0	0	1,000
Timbalier Bay	1	1	1	534	1	1	1	534	0	0	0	0
Vermilion Bay	10	21	22	15,910	8	9	10	13,343	11,895	3	9	2,200
White Lake	5	129	1	10,759	4	124	0	10,759	6,070	5	1	0
Total	68	466	346	208,619	48	344	207	145,616	119,505	76	119	43,736

[1]Includes acreage from all public notices describing marsh management activities issued between May 1980 and December 1990.
[2]Includes data from only those public notices having a final action by the Corps (permit issued or denied or application withdrawn).

Table 9. Acres of each habitat involved in NMFS habitat conservation recommendations in Louisiana, for which permits were issued from 1982 through 1990.

	Acreage proposed by applicant			Acreage permitted by Corps				Acreage conserved			
Major habitat	Dredge	Fill	Impound	Dredge	Fill	Impound	Mitigate	Dredge	Fill	Impound	Mitigate
Avicennia germinans	6	15	0	0	3	0	0	6	12	0	0
Distichlis spicata	37	135	5,210	19	44	5,167	3,492	18	91	43	3,492
Juncus roemerianus	19	49	31	17	37	31	61	2	12	0	61
Scirpus sp.[1]	12	59	0	11	14	0	12	1	45	0	12
Spartina alterniflora	129	518	10,233	79	272	8,064	6,484	50	246	2,169	6,484
Spartina patens	523	1,375	46,429	396	990	40,002	28,184	127	385	6,427	28,184
Ruppia sp.	79	114	2,490	45	92	656	3,868	34	22	1,834	3,868
Hardwood swamp	103	357	8,162	84	153	8,022	8,137	19	204	140	8,137
Freshwater marsh	321	873	40,906	320	743	40,488	31,620	1	130	418	31,620
Other marsh	125	425	165,240	102	347	164,316	4,881	23	78	924	4,881
Freshwater nonvegetated bottom	12	4	3,555	12	4	3,555	0	0	0	0	0
Freshwater submerged vegetation	133	116	190	69	64	61	3,541	64	52	129	3,541
Clay	9	7	0	0	0	0	0	9	7	0	0
Sand	297	163	0	578	128	0	0	–281	35	0	0
Shell	3	9	0	3	12	0	3	0	–3	0	3
Silt	150	78	797	146	68	775	2	4	10	22	2
Mud	3,614	20,855	197,997	2,515	1,967	191,382	27,256	1,099	18,888	6,615	27,256
Oysters	0	6	0	0	6	0	0	0	0	0	0
Miscellaneous	25	231	0	25	231	0	2	0	0	0	2
Total	5,597	25,389	481,240	4,421	5,175	462,519	117,543	1,176	20,214	18,721	117,543

[1]Prior to 1987 *Scirpus* sp. was grouped with "other marsh."

of permit applications was *S. patens* marsh.

A review of permits issued from 1982–90 reveals that the Corps accepted HCD recommendations 43% of the time (Table 11). Acceptance of HCD comments requires that the Corps deny issuance of a permit if so recommended by the HCD, or that the applicant agree to all HCD recommendations prior to permit issuance.

The Corps partially accepted HCD recommendations 34% of the time (Table 11). Partial acceptance means that the applicant agreed to some, but not all, of the HCD recommendations and the issued permit reflected partial implementation of HCD recommendations. Rejection of HCD comments, which occurred 23% of the time during the 1982–89 period, means that the Corps issued a permit when the HCD recommended denial, or that the applicant was not required to implement the HCD habitat protection recommendations. While there was no trend among years in the acceptance or partial acceptance of HCD comments, it appears as if rejection of HCD recommendations was higher in recent years (1988 and 1989). Many activities advertised in public notices issued in 1990, on which the HCD recommended revisions, are still being processed, and final action would not occur until 1991 or later.

Table 10.—Acres of each habitat involved in NMFS habitat conservation efforts in Louisiana from 1982 through 1990 which were withdrawn.

	Acreage		
Habitat	Dredge	Fill	Impound
Avicennia germinans	9	13	0
Distichlis spicata	10	37	2
Juncus roemerianus	4	17	0
Scirpus sp.	1	0	232
Spartina alterniflora	47	164	3,844
Spartina patens	101	531	7,548
Ruppia sp.	16	42	0
Hardwood swamp	11	73	400
Freshwater marsh	97	412	1,162
Other marsh	48	115	346
Freshwater submerged vegetation	43	25	13
Sand	621	169	0
Shell	11	44	0
Silt	23	16	0
Mud	1,180	3,933	3,756
Oysters	4	33	0
Miscellaneous	1	0	0
Total	2,227	5,624	17,303

It should be noted that during the period of record, the percentages of acceptance and partial acceptance are more accurately a reflection of the decision of individual applicants to agree, or partially agree, to HCD recommendations rather than the Corps' determination that applications should be revised or permits conditioned. On the other hand, rejection of HCD comments can be directly attributed to the Corps not requiring applicants to avoid, minimize, or mitigate adverse environmental impacts to what we believe to be the maximum practicable extent. Furthermore, compensatory mitigation was rarely required by the Corps and implementation of mitigation was often at the will of the permittee.

Table 11.—Annual frequency and percent (in parenthesis) of New Orleans District Corps of Engineers final actions (accept, partially accept, or reject) on NMFS recommendations concerning proposed Section 10/404 activities.

Year	Accept	Partially accept	Reject	Total
1982	30 (37)	23 (29)	27 (34)	80
1983	43 (42)	45 (44)	15 (14)	103
1984	23 (36)	33 (51)	8 (12)	64
1985	38 (53)	23 (32)	11 (15)	72
1986	21 (49)	13 (30)	9 (21)	43
1987	22 (44)	16 (32)	12 (24)	50
1988	18 (37)	12 (25)	18 (37)	48
1989	27 (50)	10 (18)	17 (31)	54
1990	13 (45)	10 (34)	6 (21)	29
Total	235 (43)	185 (34)	123 (23)	543

We anticipate increasing emphasis by the Corps on requiring permit modification or mitigation to minimize and offset adverse impacts associated with Section 10/404 activities. A memorandum of agreement between the Environmental Protection Agency and the Corps, dated 6 February 1990, requires the Corps to ensure that permit-associated impacts be avoided, minimized, and mitigated, in this sequence. The agreement further states that mitigation requirements and follow-up monitoring are to become legally enforceable conditions of Section 404 permits.

Summary

Between 1980 and 1990, the NMFS reviewed about 14,000 proposals for various coastal development activities in Louisiana. During this period, more than 600,000 acres of wetlands and adjacent water bodies were proposed for dredging, filling, or impounding. In an effort to protect valuable habitats that support the production of liv-

ing marine resources, HCD recommended that impacts to about 279,000 acres be avoided and that more than 150,000 acres of compensatory mitigation be provided. Based on data gathered between 1982 and 1990, the Corps accepted NMFS recommendations on 45% of those activities for which detailed comments were offered. Rejection or partial acceptance of NMFS recommendations resulted in the authorization of the loss or adverse modification of about 184,000 acres of wetland/aquatic habitat and approximately 7,000 fewer acres of compensatory mitigation than recommended. In addition, NMFS recommendations to the Corps were at least partially responsible for the preservation of over 63,800 acres of coastal wetlands from dredging, filling, or impounding.

Data contained in this report reflect the need for greater awareness of coastal wetland loss through the Corps' Section 10/404 permitting program. Although permitted wetland losses are only a portion of the great overall rate of wetlands lost annually in coastal Louisiana, they can be avoided, reduced, or fully offset through the Federal regulatory process. Without an accurate and continued accounting of permitted wetland alterations and mitigation measures, permitting policies are unlikely to change and the national goal of "no overall net loss of wetlands" will not be achieved.

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An Economic Analysis of Texas Shrimp Season Closures

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Introduction

The Gulf of Mexico penaeid shrimp fishery is one of the most valuable fisheries in the United States in terms of ex-vessel value, and Texas has traditionally led all Gulf states in ex-vessel value of shrimp landed. The total impact on the Texas economy, including multiplier effects, is about $580 million annually with the fishery employing some 20,000 fishermen (Cody et al., 1989). The Texas shrimp fishery relies primarily on brown shrimp, *Penaeus aztecus*, and white shrimp, *P. setiferus*. The life cycle of shrimp makes them both estuarine- and Gulf-dependent; thus, two distinct harvesting fleets have evolved, inshore and offshore.

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ABSTRACT—Management of the Texas penaeid shrimp fishery is aimed at increasing revenue from brown shrimp, Penaeus aztecus, *landings and decreasing the level of discards. Since 1960 Texas has closed its territorial sea for 45–60 days during peak migration of brown shrimp to the Gulf of Mexico. In 1981 the closure was extended to 200 miles to include the U.S. Exclusive Economic Zone. Simulation modeling is used in this paper to estimate the changes in landings, revenue, costs, and economic rent attributable to the Texas closure. Four additional analyses were conducted to estimate the effects of closing the Gulf 1- to 4-fathom zone for 45 and 60 days, with and without effort redirected to inshore waters. Distributional impacts are analyzed in terms of costs, revenues, and rents, by vessel class, shrimp species, vessel owner, and crew.*

An important aspect of the inshore fishery relates to the function of bays in the life cycle of shrimp. Penaeid shrimp spawn in the Gulf of Mexico and larvae are carried into estuaries. During the early stages of shrimp growth, marshes and shallow bay areas serve as nursery grounds. As juvenile shrimp grow and mature, they emigrate offshore to the open waters of the Gulf.

The timing and duration of this cycle differs between species, but the major harvesting implications remain the same. During bay shrimping seasons, small shrimp found in shallow bays and near-offshore areas are subjected to harvest by inshore commercial (food and bait) and recreational fishermen before they move to deeper water and become available to the offshore fleet. The offshore fleet is characterized by large vessels capable of staying offshore for long periods of time. They target larger shrimp that roam deeper waters, and the amount of shrimp available to them is partially a function of the inshore harvest.

Since 1960, Texas has enacted a 45- to 60-day closure of its territorial sea from the 4-fathom depth contour to 9 n.mi. from shore during peak migration of brown shrimp to the Gulf of Mexico. In 1981, as mandated by the Gulf of Mexico Shrimp Management Plan, the Texas closure was extended to 200 n.mi. to include the U.S. Exclusive Economic Zone (EEZ)[1]. During this closure, however, the shallow offshore area from the shoreline to 4 fathoms deep was left open to white shrimp fishing. The economic thrust behind the closure is to increase the value of the brown shrimp harvest by protecting brown shrimp until they reach a larger, more valuable size, as well as to reduce waste through discarding. In conjunction with the 200-mile closure, the Texas Legislature repealed the count laws to reduce discarding.

The Texas Legislature historically has managed the fishery to maximize ex-vessel value of shrimp landed (Cody et al., 1989). In 1985 the Texas Parks and Wildlife Commission was granted authority to regulate the shrimp fishery in Texas's bays and territorial sea. The Texas Shrimp Fishery Management Plan was adopted in 1989, and in 1990 the 4-fathom offshore area, previously left open to white shrimp fishing, was closed[2].

Since 1981, the year the EEZ closure regulation began, the National Marine Fisheries Service (NMFS) has annually assessed the effects of the closure in terms of size distribution of shrimp, catch patterns in the fishery, overall

[1]In 1986, 1987, and 1988, the Texas closure was modified to extend to only 15 n.mi.

[2]There has been speculation that leaving the 4-fathom zone open could have detrimental effects on the overall fishery for the following reasons: 1) Enforcement of the closure is more difficult with this depth zone left open, 2) one-third of all brown shrimp discards are coming from the 4-fathom zone during the closure months, and 3) excess pressure on spawning white shrimp may have caused a reduction in recruitment of white shrimp to the fishery (data indicate a decline in white shrimp recruitment in Texas waters since 1981 (Cody et al., 1989)).

yield, and value of landings associated with changes in yield (Klima et al., 1983–85; Nichols, 1983–85, 1987; and Poffenberger, 1982, 1984, 1986a,b,c). NMFS uses the results for a given year the closure is in effect, and simulates for that year what landings would have been if there had been no closure. In contrast to the yearly evaluations conducted by NMFS, this study uses simulated average fishery conditions for the pre-closure period (1963–80) and compares the results to a closure (1981–85) simulation average, holding all environmental conditions constant. In other words, this analysis compares a simulated pre-closure average to a simulated closure average.

The purpose of this study was to analyze the economic effects of the 200-mile Texas closure as well as the economic effects of a total offshore closure including the 4-fathom zone. Distributional impacts were examined in terms of costs, revenue, and rent, by vessel class, shrimp species, vessel owner, and crew. Because the closure can range from 45 to 60 days, depending on biological conditions in the fishery, this study examined the effects of closing the fishery for the minimum and maximum number of days. Simulations also were run with and without effort redirected to inshore waters; the Texas closure caused a redirection of effort into the 4-fathom zone offshore, and it is expected that closing the 4-fathom zone will prompt a redirection of effort to inshore waters. Compliance of 100% was assumed (i.e., no illegal effort) when the 4-fathom zone was closed because shrimp vessels would have no reason to be in offshore waters and enforcement of the closure would be more effective. The policies analyzed are as follows:

1) 200-mile, 45-day closure, with the 4-fathom zone open;

2) 200-mile, 45-day closure, with the 4-fathom zone closed[3];

3) 200-mile, 45-day closure, with the 4-fathom zone closed and effort redirected inshore;

4) 200-mile, 60-day closure, with the 4-fathom zone closed;

5) 200-mile, 60-day closure, with the 4-fathom zone closed and effort redirected inshore.

Methodology

Model Description

The General Bioeconomic Fishery Simulation Model (GBFSM) was developed specifically for annual crop fisheries, and it is particularly applicable to the Gulf shrimp fishery (Grant et al., 1981; Griffin and Grant, 1982). The simulation model, or adaptations of GBFSM, have been used in several practical applications prior to this analysis (Blomo et al., 1982; Blomo et al., 1978; Griffin et al., 1979, 1981, 1990; Griffin and Grant, 1982). In the GBFSM, effects are assessed in terms of total harvest—species, size class, and seasonal distribution of the harvest; total revenue, total costs, and rent in the fishery; and distribution of revenue, costs, and rent among different classes of fishing vessels.

The user may select any number of species, size classes, fishing areas, depths, and vessel classes for inclusion in the model. The time-step, extent, and resolution of model output are also variable. The model is currently set with 8 fishing areas, 6 shrimp size classes, and 3 vessel classes (Table 1). The model is also set with 144 time steps, i.e., the model goes through its cycle—recruitment, growth, movement, mortality—144 times per year, or about once every 2.5 days.

The biological submodel represents recruitment of new organisms into the fishery by species, area, and time frame.

Table 1.—Characteristics of categories into which shrimp vessels, shrimp landings, and fishing areas were placed for modeling purposes.

Category	Fishing areas (Depth in fm)	Shrimp (No./lb)	Vessels
1	<1 (Nursery)	<20	Unregistered, inshore
2	<1 (Bays)	20 – 30	Registered, Texas based[1]
3	1 – 5	31 – 50	Registered, non-Texas based[2]
4	6 – 10	51 – 67	
5	11 – 15	68 – 116	
6	16 – 20	117 – 160	
7	21 – 25		
8	>25		

[1]Usually less than 55 feet in length.
[2]Usually greater than 55 feet in length.

Organisms grow and move from one size class to another and mortality results from both natural causes and fishing. Bait and recreational fishing occur within the model in inshore depths only. The model represents fishing effort exerted on each species by vessel class, depth zone, area, and time frame. Nominal days fished are exogenous to the model and are converted to real days fished based on the relative fishing power of vessels involved. The economic submodel represents monetary costs of fishing, value of harvest, and rent to the fishery. The economic submodel is built on top of the biological submodel and calculates economic effects based upon the biological effects of any proposed management strategy put into the model.

Reported shrimp landings for 1963–85 were obtained from NMFS master files. These data are categorized into landings by area, species, size class, depth zone, and month for the entire 23-year period except 1969 and 1984; these years were excluded because effort data was incomplete when this study was undertaken. Nominal days fished were derived from the effort expansion data developed by Nichols (NMFS Pascagoula Laboratory) and were categorized by area, species, vessel class, depth zone, and time period. Given these data, it is possible to tune and validate the model by comparing model simulations to historical landings.

Model Tuning and Validation

Tuning the model requires the biological coefficients in the model to be set to the best estimate of values (obtained from Cody et al., 1989, and the Texas Parks and Wildlife Department[4]) and then adjusted until the tuned model depicts reality. The first step is to use average effort patterns and levels from the NMFS data set for the pre-closure period (1963–80) to generate average landings for the same period. These landings are expressed as total landings, landings by month, landings by depth zone, and landings by size class for both brown and white shrimp. The various

[3]Because this study was conducted prior to implementation of the 4-fathom zone closure, 1981–85 fishing patterns were used.

[4]Texas Parks and Wildlife Department, 4200 Smith School Road, Austin, TX, 78744. Unpubl. data.

biological coefficients within the model are then adjusted (within the range of realistic possibilities) until the simulated landings match the historical average in terms of depth zone, size class, seasonal distribution, and total landings.

The first step in model validation is to test the tuned model against a time period not used in the tuning process. Average effort patterns and levels for the 1981–85 period are inserted into the tuned model and the average landings generated are compared to reported average landings for the closure period.

The second step in validation indicates how well the model depicts landings over the range of effort levels actually exerted between 1963 and 1985. The model is run through a 21-year simulation with the actual effort for each year (1963–85) imposed. All biological coefficients remain constant. This procedure generates a yield plot of landings (with environmental conditions held constant) for the 21-year period which is compared to actual data points to determine how well simulated landings fit within the range of actual data points. The tuning and validation process was carried out individually for brown and white shrimp[5].

Policy Analysis

The analysis presented herein is a short-run analysis that estimates the effects the closure had on landings, revenue, costs, and rent to the shrimp fishery. To measure the effects of the closure and avoid capturing the effects of different effort levels, effort must be held constant throughout the analysis. Figure 1 helps illustrate this point. The 200-mile closure forced a change in the offshore shrimp fleet's fishing patterns. Yield curve Y1 is assumed to be the yield curve before the closure, and Y2 is the yield curve after the closure. The question is, what effect did the closure have on landings, revenue, costs, and rent to the fishery, omitting the effects of different effort levels. Movement from A to B in Figure 1 represents a change in landings due to an increase in effort from E1 to E2 under the pre-closure scenario, whereas movement from B to C represents a change in landings due to a policy change at a given level of effort. The change in landings induced by a change in policy, and the consequent effects on revenue, cost, and rent, while holding effort constant, is the subject of this paper.

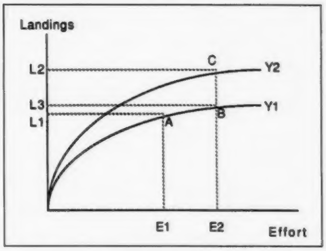

Figure 1.—Comparison of different fishing patterns at equal total effort levels.

To compare economic rent between the pre-closure and closure offshore fishing patterns, the pre-closure simulation is set to economic equilibrium, i.e., rent is zero. This is accomplished by establishing the appropriate variable costs by vessel class[6], then adjusting fixed costs (including opportunity costs) until rent to vessel owners is equal to zero. Figure 2 represents the theoretical framework upon which this process is based. The R1 curve represents the revenue curve associated with the pre-closure offshore fishing patterns. Because this analysis assumes an equilibrium position for the pre-closure offshore fishing patterns, total costs represented by C1 must equal R1 at effort level E2. This implies rent is zero. The closure affects revenue and cost as shown by curves R2 and C2, respectively. Cost is affected by the closure because crew shares and packing charges are calculated as a percentage of landings; if landings increase, so do crew shares and packing charges. The closure causes revenue to increase from B to C, costs to increase from B to D, and rent is measured from D to C.

Because effort levels in the pre-closure and closure periods were not the same (Table 2), the effort level in the pre-closure period was set to the effort level of the closure period by the following procedure. Days fished for brown shrimp in the inshore area increased substantially over the entire period considered (1963–85). This increase in days fished is assumed to be unrelated to the closure because it began before the closure was implemented and would have continued with or without the closure. Therefore, inshore effort was held constant at the 1981–85 level for both the pre-closure and closure periods[7]. Environmental conditions, unit price received, and unit costs of fishing also were held constant.

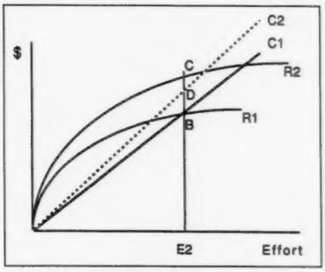

Figure 2.—Setting of zero rents to each vessel class (economic equilibrium) for base simulation.

The average offshore effort level was greater in the closure period (1981–85) than in the pre-closure period (1963–80). In the offshore area, average days

Table 2.—Average days fished for brown and white shrimp.

	Brown shrimp		White shrimp	
Years	Days fished inshore	Days fished offshore	Days fished inshore	Days fished offshore
1963–80	2,458	44,679	7,698	12,567
1976–80	4,008	49,510	8,158	13,551
1981–85	9,935	46,150	9,623	16,296

[5]The results of tuning and validating the model are too lengthy to present here. They are reported in Griffin et al. (1990) and will be provided by the author upon request.

[6]Because out-of-state vessels spend a limited amount of time in Texas, all costs for vessel class 3 were categorized as variable.

[7]The closure may have had a dampening effect on inshore effort expansion because some effort may have been redirected inshore by smaller boats (Nance et al., 1991). Because large vessels could fish in the 1–4 fathom area offshore during the closure, increased crowding in the 1–4 fathom area forced smaller boats into the inshore area. However, for this analysis, fishing patterns and effort levels were held constant for the inshore area in both the pre-closure and closure periods.

fished for brown shrimp in 1981–85 increased by 1,471 over the 1963–80 average. Average days fished for white shrimp in the offshore area increased also, particularly in June and July (Griffin et al., 1990) because the 1–4 fathom area offshore was left open to white shrimp harvesting during the closure. Offshore fishing patterns for the 1963–80 period were held constant but the level of effort was inflated to the average 1981–85 offshore effort level.

Results

200-mile, 45-day Closure, 4-fathom Zone Open

Fishing Patterns

Total fishing effort for both brown and white shrimp increased from the pre-closure to closure periods (Table 3). Brown shrimp effort in the inshore area (depth zone 2) increased by a factor of 4, and brown shrimp effort in the offshore depths shifted from depth 6 (16–20 fathoms) to depth 8 (>25 fathoms). When effort in the pre-closure period was inflated to closure levels and compared to the closure period (Table 3), total effort was the same but the distribution of effort between brown and white shrimp changed. The average number of days fished for brown shrimp declined by 2,000 days, and the average number of days fished for white shrimp increased by 2,000 days. Vessels that had been fishing in the EEZ from mid-May through mid-July in the pre-closure period now must either fish in the EEZ illegally, fish off other Gulf states, fish in Mexican waters illegally, not fish at all, or redirect effort to inshore areas to fish for brown shrimp, or to the 4-fathom zone offshore to fish for white shrimp. Effort on brown shrimp was reduced overall, though some of that effort was redirected to white shrimp, particularly in June when there was a shift from depth 4 (6–10 fathoms) to depth 3 (1–5 fathoms). Fishermen apparently spent more time fishing for white shrimp when the EEZ was closed than when it was open.

Brown Shrimp Landings

Annual brown shrimp landings increased from 33.8 million pounds in the pre-closure simulation to 35.4 million pounds in the closure simulation (Table 4). Landings of medium sized shrimp (sizes 3 and 4) decreased in the closure simulation, whereas landings of large sized shrimp (sizes 1 and 2) increased. Landings of the smallest shrimp (sizes 5 and 6) also increased in the closure simulation, probably due to rescission of the count laws. The increase in landings of small shrimp accounted for most of the increase in total landings. The closure simulation also revealed a reduction in discards. Brown shrimp discards generated by the pre-closure simulation were 2.4 million pounds, compared to 0.76 million pounds under the closure simulation.

To distinguish between changes in landings and discards attributable to the closure and changes attributable to elimination of the count laws, two additional simulations were performed: A simulation with closure effort patterns and the old count laws in effect (65 whole shrimp per pound) and a simulation with pre-closure effort patterns and no count laws. Compared to the pre-closure simulation with the count laws, the closure simulation with count laws produced virtually no change in total landings, but landings were distributed toward the larger, more valuable size classes. A small reduction in discards resulted from reduced effort during the 45-day closure. The pre-closure simulation with no count laws produced a 2-million-pound increase in total landings (compared to the pre-closure simulation with count laws), but this increase occurred in the smallest size classes; there was no redistribution of the harvest toward larger size shrimp. Discards were virtually eliminated, which translated to increased landings of smaller shrimp. These simulations indicate that the closure resulted in redistribution of the brown shrimp harvest from mid-sized shrimp to large shrimp, and elimination of the count laws resulted in a substantial reduction of discards.

White Shrimp Landings

Simulations for white shrimp produced an increase in total landings in the closure period. Pre-closure effort patterns landed 11.49 million pounds of white shrimp compared to the closure effort patterns which landed 12.97 million pounds (Table 5). White shrimp landings were slightly higher for all size

Table 3.—Average days fished for all vessels.

	Brown shrimp			White shrimp		
Depth zone	Pre-closure days fished	Closure days fished	Pre-closure inflated	Pre-closure days fished	Closure days fished	Pre-closure inflated
1	0	0	0	0	0	0
2	2,305	9,629	9,629	7,143	9,321	9,321
3	281	697	281	3,462	4,003	3,579
4	2,137	3,345	2,325	7,400	9,707	8,052
5	11,372	11,077	12,374	996	999	1,084
6	12,807	10,708	13,935	182	248	198
7	7,881	7,363	8,575	32	50	34
8	8,593	11,558	9,350	26	59	28
Total	45,376	54,377	56,469	19,241	24,387	22,296

Table 4.—Distribution of brown shrimp landings (in thousands of pounds).

Depth	Discards	Size 1	Size 2	Size 3	Size 4	Size 5	Size 6	Total
Pre-closure simulation								
1	0	0	0	0	0	0	0	0
2	216	0	4	217	466	1,946	1,995	4,627
3	413	0	2	31	44	70	22	170
4	783	20	311	992	290	241	6	1,860
5	678	357	2,045	4,797	967	219	0	8,386
6	285	665	3,002	4,298	1,129	90	0	9,184
7	32	862	2,197	1,521	183	10	0	4,773
8	1	1,998	2,168	641	19	0	0	4,826
Total	2,408	3,902	9,729	12,497	3,098	2,576	2,023	33,826
Closure simulation								
1	0	0	0	0	0	0	0	0
2	42	0	4	217	466	1,946	2,169	4,801
3	281	0	3	58	62	217	151	490
4	213	24	421	1,173	249	761	48	2,676
5	173	333	1,989	4,447	693	574	0	8,036
6	41	749	2,854	2,956	552	158	0	7,269
7	9	907	2,457	1,489	112	20	0	4,985
8	1	2,389	3,598	1,176	17	1	0	7,180
Total	760	4,402	11,326	11,516	2,151	3,677	2,368	35,437

Table 5.—Distribution of white shrimp landings (in thousands of pounds).

Depth	Discards	Size 1	Size 2	Size 3	Size 4	Size 5	Size 6	Total
Pre-closure simulation								
1	0	0	0	0	0	0	0	0
2	300	84	880	1,817	980	1,323	504	5,588
3	399	325	498	440	252	154	18	1,686
4	182	819	1,365	966	300	101	2	3,554
5	5	160	184	137	68	2	0	552
6	0	43	29	17	9	0	0	98
7	0	9	2	1	0	0	0	12
8	0	0	0	0	0	0	0	0
Total	886	1,440	2,958	3,378	1,609	1,580	524	11,490
Closure simulation								
1	0	0	0	0	0	0	0	0
2	219	84	880	1,817	980	1,323	585	5,669
3	0	410	509	454	285	424	190	2,271
4	0	904	1,471	1,224	440	384	38	4,462
5	0	111	196	120	65	5	0	497
6	0	19	19	11	10	0	0	58
7	0	9	1	0	0	0	0	10
8	0	0	0	0	0	0	0	0
Total	219	1,537	3,076	3,626	1,780	2,136	813	12,967

classes, though most of the increase in total landings came from the two smallest size classes (sizes 5 and 6). White shrimp discards were 0.885 million pounds under the pre-closure simulation and 0.219 million pounds under the closure simulation. When the simulation was performed under closure effort patterns but with the old count laws, total landings fell by 0.8 million pounds and discards increased by the same amount. Under the pre-closure simulation with no count laws (other than the fall inshore count law), landings increased 0.5 million pounds and discards decreased by 0.5 million pounds. These results indicate that discards were traded for landings when the count laws were repealed.

Economics

Cost and returns information for the pre-closure and closure simulations, categorized by vessel class and shrimp species, is outlined in Tables 6 and 7. For vessel class 1, the $0.159 million increase in rent under the closure simulation was primarily due to a slight increase in landings and revenue, as fixed and variable costs remained relatively constant. For vessel class 2, fishing patterns under the closure simulation led to a minor increase in costs and a substantial increase in landings and revenue, which translated into a $4.855 million increase in rent. Even though out-of-state vessels (vessel class 3) incurred a substantial increase in variable costs under the closure simulation, these costs were more than offset by increases in landings and revenue, such that vessel class 3 realized a $2.042 million increase in rent.

In the base simulation, with rent to the fishery equal to zero, rent for brown shrimp was –$0.557 million and rent for white shrimp was $0.557. Under the closure simulation, rent for brown shrimp increased to $7.438 million (a $7.995 million increase) and rent for white shrimp fell to –$0.382 million (a $0.939 million decrease). Total rent to vessel owners under the closure simulation was $7.056 million, with about 71% of the rent going to Texas vessels and 29% to out-of-state vessels. When the $1.851 million increase in crew rent[8] was added to owners' rent, the total increase in economic rent attributable to the closure was $8.907 million.

[8]The model takes into account the number of crew members for each vessel and the percentage of revenues attributable to the crew. Because the model assumes all vessels are owner-operated, vessel class 1 (unregistered inshore boats) has 0 crew members and 0% crew share. Vessel classes 2 and 3 both have 2 crew members who receive a 20% share of revenues.

Table 6.—Pre-closure simulation (all values in thousands except days fished and price/pound).

	Vessel owners' costs and returns					
	Vessel class			Shrimp species		
Item	1	2	3	Brown	White	Total owners
Days fished	16,286	54,859	7,619	56,468	22,296	78,764
Price/pound	1.84	3.29	3.31	3.05	3.04	3.04
Landings	7,829	32,581	4,907	33,827	11,490	45,317
Revenue	14,414	107,294	16,257	103,057	34,908	137,965
Variable cost	3,241	64,990	16,257	65,038	19,450	84,488
Fixed cost	11,173	42,304	0	38,576	14,901	53,477
Total cost	14,414	107,294	16,257	103,614	34,351	137,965
Rent	0	0	0	–557	557	0

	Crews' costs and returns		
	Vessel class		
Item	2	3	Crews + owners
Revenue	21,459	3,251	
Variable cost	652	98	
Fixed cost	20,807	3,153	
Total cost	21,459	3,251	
Rent	0	0	0

Table 7.—200-mile, 45-day closure simulation, 4-fathom zone open (all values in thousands except days fished and price/pound).

	Vessel owners' costs and returns					
	Vessel class			Shrimp species		
Item	1	2	3	Brown	White	Total owners
Days fished	16,203	54,456	8,106	54,378	24,387	78,765
Price/pound	1.81	3.32	3.18	3.09	2.93	3.05
Landings	8,039	34,096	6,270	35,437	12,968	48,405
Revenue	14,557	113,138	19,948	109,646	37,997	147,643
Variable cost	3,225	65,979	17,906	65,259	21,851	87,110
Fixed cost	11,173	42,304	0	36,949	16,528	53,477
Total cost	14,398	108,283	17,906	102,208	38,379	140,587
Rent	159	4,855	2,042	7,438	–382	7,056

	Crews' costs and returns		
	Vessel class		
Item	2	3	Crews + owners
Revenue	22,628	3,990	
Variable cost	682	125	
Fixed cost	20,807	3,153	
Total cost	21,489	3,278	
Rent	1,139	712	8,907

200-mile, 45-day Closure, 4-fathom Zone Closed

The Texas Parks and Wildlife Department recently modified the Texas closure to include closure of the 4-fathom zone offshore. This narrow, near-shore depth zone remained open to daytime white shrimp fishing during the Texas closure until 1990. Effort data in the previous simulation included illegal effort exerted in offshore waters during the closure. This analysis closed all offshore waters to shrimping from 1 June through 15 July and assumed 100% compliance by fishermen.

Closing the 4-fathom zone in conjunction with the EEZ closure caused a \$0.103 million drop in rent for vessel class 1 (compared to the EEZ closure with the 4-fathom zone open) due to a greater decline in revenue than total cost (Table 8). Vessel class 2, on the other hand, benefited from a decline in total costs which more than offset the drop in revenue, and rent increased by \$1.182 million. Out-of-state vessels also experienced a cost savings greater than the loss in revenue, and rent to vessel class 3 increased by \$0.679 million.

Landings of brown shrimp fell by 610,000 pounds and revenue remained almost unchanged (due to a higher price per pound), but a decline in total costs resulted in a \$2.102 million increase in rent for this species. Though the white shrimp fishery also experienced a drop in total costs, it was not enough to offset the decline in landings and revenue, and rent to the white shrimp fishery fell by \$0.344 million. Total rent to vessel owners increased \$1.758 million to \$8.814 million under this scenario. Rent to crew members decreased \$0.219 million because of the decline in landings. Total rent to the fishery was \$10.446 million, a \$1.63 million increase over the EEZ closure with the 4-fathom area open.

200-mile, 45-day Closure, 4-fathom Zone Closed, Effort Redirected Inshore

When the closure regulation first went into effect in 1981, effort in the 4-fathom zone expanded. It was assumed closing the 4-fathom zone would lead to a redirection of effort into the inshore waters. For this simulation, only vessels that were fishing in both the 4-fathom zone and inshore waters were allowed to redirect effort (from the 4-fathom zone to inshore waters).

Compared to the prior simulation (without redirected effort), landings and revenue for vessel class 1 declined slightly, total costs rose, and rent to vessel class 1 fell \$0.189 million to –\$0.133 million (Table 9). Even though landings increased, vessel class 2 incurred a decline in revenue because the increase in landings was made up of smaller shrimp from inshore waters. Coupled with an increase in total cost, due to more days fished, vessel class 2 lost \$1.08 million in rent. Landings and revenue for vessel class 3 declined, costs remained stable, and rent fell by \$0.181 million.

Though landings of brown shrimp increased slightly, the drop in revenue and increase in total cost led to a \$1.503 million loss in rent to the brown shrimp fishery. Only the white shrimp fishery benefited under this simulation. Landings were virtually unchanged, but the decline in total cost was greater than the fall in revenue, which resulted in a \$0.053 million boost in rent. Vessel owners' rents under this scenario shrank to \$7.364 million, compared to \$8.814 million under the previous simulation, for a \$1.45 million loss due to redirection of effort to inshore waters. As with vessel owners, crews' revenues dropped due to landings of smaller, less valuable shrimp. When the crews' economic losses were added to the vessel owners' losses, rent fell from \$10.446 million (under the previous simulation) to \$8.847 million, for a \$1.599 million loss in economic rents to the fishery. Compared to the first closure simulation, closing the 4-fathom zone and redirecting effort

Table 8.—200-mile, 45-day closure simulation, 4-fathom zone closed (all values in thousands except days fished and price/pound).

	Vessel owners' costs and returns					
	Vessel class			Shrimp species		
Item	1	2	3	Brown	White	Total owners
Days fished	16,049	51,970	7,574	52,079	23,514	75,593
Price/pound	1.80	3.36	3.22	3.15	2.89	3.08
Landings	8,000	33,396	6,119	34,827	12,688	47,515
Revenue	14,423	112,228	19,681	109,652	36,680	146,332
Variable cost	3,194	63,887	16,960	63,128	20,913	84,401
Fixed cost	11,173	42,304	0	36,984	16,493	53,477
Total cost	14,367	106,191	16,960	100,112	37,406	137,518
Rent	56	6,037	2,721	9,541	–726	8,814

	Crews' costs and returns		
	Vessel class		
Item	2	3	Crews + owners
Revenue	22,446	3,936	
Variable cost	668	122	
Fixed cost	20,807	3,153	
Total cost	21,475	3,275	
Rent	971	661	10,446

Table 9.—200-mile, 45-day closure simulation, 4-fathom zone closed, effort redirected inshore (all values in thousands except days fished and price/pound).

	Vessel owners' costs and returns					
	Vessel class			Shrimp species		
Item	1	2	3	Brown	White	Total owners
Days fished	16,204	52,827	7,590	53,054	23,567	76,621
Price/pound	1.80	3.33	3.22	3.12	2.88	3.06
Landings	7,944	33,567	6,054	34,879	12,686	47,565
Revenue	14,265	111,694	19,481	108,855	36,585	145,440
Variable cost	3,225	64,433	16,941	63,638	20,961	84,599
Fixed cost	11,173	42,304	0	37,180	16,297	53,477
Total cost	14,398	106,737	16,941	100,818	37,258	138,076
Rent	–133	4,957	2,540	8,037	–673	7,364

	Crews' costs and returns		
	Vessel class		
Item	2	3	Crews + owners
Revenue	22,339	3,896	
Variable cost	671	121	
Fixed cost	20,807	3,153	
Total cost	21,478	3,274	
Rent	861	622	8,847

yielded a $0.308 million increase in rent to vessel owners and a $0.368 million decrease in rent to crews. The net effect was a $0.060 million loss in rent to the fishery.

200-mile, 60-day Closure, 4-fathom Zone Closed

This simulation extended the closure period to 60 days, from 15 May to 15 July, closed all offshore waters including the 4-fathom zone, and allowed no illegal effort. It is the same scenario as the second simulation (to which it will be compared), except the closure lasted 60 days instead of 45.

Vessel class 1 was virtually unaffected by the 15-day extension (Table 10). Landings for vessel class 2 declined, and even though they received a higher price per pound for their shrimp, revenue also fell. The decline in days fished however, translated into a considerable reduction in total operating costs which more than made up for the drop in revenue, and this vessel class realized an increase in rent of about $1.09 million. Landings and revenue for vessel class 3 increased, costs remained stable, and rent increased by $0.484 million.

Landings decreased for both brown and white shrimp. Revenue from white shrimp declined, but revenue from brown shrimp increased because of the higher price per pound received for larger shrimp. Rent to the brown shrimp fishery increased by $1.953 million and rent to the white shrimp fishery decreased by $0.374. The increase in rent to vessel owners was $1.579 million, for a total of $10.393 million. When crews' rents were added to owners' rents, total rent to the fishery climbed to $11.984 million, which was $1.538 million more than the same scenario under a 45-day closure. Compared to the first closure simulation, rent to vessel owners was $3.337 million higher, rent to crews was $0.260 lower, and the net increase in rent from closing the 4-fathom zone for 60 days was $3.077 million.

200-mile, 60-day Closure, 4-fathom Zone Closed, Effort Redirected Inshore

This simulation was the same as the previous analysis but allowed some effort to be redirected to inshore waters. Compared to the prior simulation, redirection of effort caused a reduction in net economic benefits. Days fished for vessel class 1 increased, total costs rose, landings and revenue fell, and rent dropped to –$0.176 million, a $0.237 million loss (Table 11). Vessel class 2 was hurt the most by redirected effort. Days fished and total costs increased, revenue declined due to a lower average price per pound for shrimp, and rent fell by $1.49 million to $5.637 million. For vessel class 3, costs remained stable, revenue declined, and rent fell by $0.254 million.

The results by species revealed almost no change for white shrimp but a considerable change for the brown shrimp fishery. A lower price per pound, reduced revenue, and increased costs due to more days fished resulted in a $2.0 million loss in rent to the brown shrimp fishery. Rent to vessel owners was $8.413 million, a $1.981 million decline. Crews' economic rent also shrunk under this simulation such that the total loss in rent from redirected effort was $2.202 million. Although total rent to the fishery fell from $11.983 million to $9.782 million because of redirected effort, it remained $0.875 million higher than under the first closure simulation.

Conclusions

The 1-year impact analysis of the Texas closure (45 days, 4-fathom zone open) revealed a positive effect on all vessel classes (some more than others) and on all crews; the total gain in rent from the closure was $8.907 million. Closing the 4-fathom zone and extending the closure to 60 days increased rent to the fishery by more than $3 million (compared to the 45-day closure

Table 10.—200-mile, 60-day closure simulation, 4-fathom zone closed (all values in thousands except days fished and price/pound).

	Vessel owners' costs and returns					
	Vessel class			Shrimp species		
Item	1	2	3	Brown	White	Total owners
Days fished	16,037	49,784	7,512	50,613	22,720	73,333
Price/pound	1.80	3.41	3.23	3.20	2.86	3.11
Landings	8,000	32,739	6,240	34,677	12,302	46,979
Revenue	14,425	111,486	20,172	110,880	35,203	146,083
Variable cost	3,191	62,055	16,967	62,249	19,964	82,213
Fixed cost	11,173	42,304	0	37,138	16,339	53,477
Total cost	14,364	104,359	16,967	99,387	36,303	135,690
Rent	61	7,127	3,205	11,493	−1,100	10,393

	Crews' costs and returns		
	Vessel class		
Item	2	3	Crews + owners
Revenue	22,297	4,034	
Variable cost	655	125	
Fixed cost	20,807	3,153	
Total cost	21,462	3,278	
Rent	835	756	11,984

Table 11.—200-mile, 60-day closure simulation, 4-fathom zone closed, effort redirected inshore (all values in thousands except days fished and price/pound).

	Vessel owners' costs and returns					
	Vessel class			Shrimp species		
Item	1	2	3	Brown	White	Total owners
Days fished	16,204	50,890	7,529	51,790	22,833	74,623
Price/pound	1.80	3.36	3.23	3.16	2.85	3.08
Landings	7,919	32,974	6,146	34,738	12,301	47,039
Revenue	14,222	110,678	19,879	109,671	35,108	144,779
Variable cost	3,225	62,737	16,928	62,833	20,057	82,890
Fixed cost	11,173	42,304	0	37,345	16,132	53,477
Total cost	14,398	105,041	16,928	100,178	36,189	136,367
Rent	−176	5,637	2,951	9,493	−1,081	8,412

	Crews' costs and returns		
	Vessel class		
Item	2	3	Crews + owners
Revenue	22,136	3,976	
Variable cost	659	123	
Fixed cost	20,807	3,153	
Total cost	21,466	3,276	
Rent	670	700	9,782

with the 4-fathom area open) and reduced discards to 42,000 pounds. This closure scenario seems to represent the best alternative for achieving the objectives of the closure management policy: Elimination of discards and increasing the value of the brown shrimp harvest. When effort was redirected to inshore waters, benefits of the 60-day closure declined, but were still greater than the benefits from the original closure. The only segment of the fishery which did not benefit from the 60-day closure was the crew. All four scenarios that closed the 4-fathom zone left the crews worse off than the original Texas closure.

Relevant to any discussion of policy analysis must be consideration of what happens in the industry when you make vessel owners better off. In the Gulf of Mexico shrimp fishery, the objectives are to implement management policies which increase economic benefits to the participants and to society as a whole. In an open-access fishery such as the Gulf shrimp fishery, it is useful to consider the implications of increasing economic rents to the participants. As rents rise, due to a price increase or a new policy, it is likely that effort will expand and absorb the excess profit until the fishery reaches a new equilibrium and rent is again driven to zero. Without some form of effort limitation or limited entry program, any policy that generates an increase in rent for the fishery will be short-lived in its effectiveness.

The above discussion assumes that inshore effort, environmental conditions, prices, and unit costs are all held constant. In the real world, however, these elements are not held constant and an expansion of effort may not be the result. For example, Griffin and Beattie (1978) examined the impact of closing Mexico's 200-mile offshore fishing zone on the U.S. Gulf of Mexico shrimp fishery. Their results indicated a negative impact on the shrimp fleet, which implied vessels would leave the industry in the long run. However, because of the price structure at that time (high price for shrimp, low cost for fuel) and the backlog of orders for new vessels, they concluded that shrimp fishermen were making large enough profits to withstand being shut out of Mexican waters and still remain profitable. Thus, even though the closure of Mexico's waters had a negative impact on the U.S. Gulf shrimp fleet, market conditions at that time were so favorable that the industry expanded anyway, though it expanded less than it would have if Mexican waters had remained open.

The Texas closure had the same type of effect, but in the opposite direction. Inshore effort increased dramatically during 1979–85, which implies that fewer brown shrimp reached offshore waters. Second, double-digit inflation in the late 1970's and early 1980's caused unit costs of shrimping to increase. Third, shrimp culture was rapidly expanding around the world, and the increase in U.S. shrimp imports caused the price of shrimp to remain relatively constant while unit costs increased. Thus, unfavorable conditions put pressure on vessels to exit the industry, whereas the effects of the Texas closure would induce vessels to enter the industry.

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Subsurface Fish Handling to Limit Decompression Effects on Deepwater Species

FRANK A. PARRISH and ROBERT B. MOFFITT

Introduction

Fish commonly suffer barotrauma caused by rapid decompression as they are hauled to the surface by conventional fishing techniques. The problems are more serious for fish caught at greater depths and especially for physoclistous fishes with closed swim bladders. Common physical effects of such drastic volume changes are everted stomachs, eyes forced from orbits, and distortion of scales and subcutaneous flesh.

Barotrauma can have implications for the success of some research investigations. Regurgitation and stomach eversion adversely affect research results in dietary studies (Bowman, 1986). Fish in tag-and-recovery studies suffer increased mortality and their natural behavior may be altered (Grimes et al., 1983; Matthews and Reavis, 1990). Hauling snappers to the surface at slow or controlled rates does not greatly reduce the effects of barotrauma (Haight, 1989). Attempts to relieve distended air bladders at the surface by puncture using hypodermic syringe needles 1) require repositioning of fish stomachs, 2) involve more handling, and 3) do not eliminate the risk of internal injury during hauling. An injured bladder may not be capable of regulating volume properly, or at best it may require a prolonged recovery period (Harden-Jones, 1957). Thus, fish returned to native depths with artificially vented gas bladders may have trouble maintaining normal buoyancy and behave abnormally for an unknown period of time after release.

Studies (Matthews and Reavis, 1990; DeMartini et al.[1]) have shown that fish tagged at depth by scuba divers provide a greater number of tag returns than those tagged at the surface by conventional techniques. Methods for successful tagging at depths inaccessible to scuba divers have been developed by Grimes et al. (1983) using breakaway hooks and by Priede and Smith (1986) using an ingestible acoustic tag. Unfortunately, neither method provides information as to the size (or even species in the case of Grimes et al. (1983)) of the tagged individual at the time of tagging, and both methods are poorly suited to multispecies fishery situations.

In the course of studying the juvenile Hawaiian snapper, *Pristipomoides filamentosus*, we have found it necessary to tag individuals acoustically to evaluate their diel movement patterns. However, these fish routinely suffer severe barotrauma when hauled to the surface from their normal depths of 65–100 m (Parrish, 1989). Assuming unrestricted expansion, a fish brought from 65 m may experience a 7.5-fold increase in gas volume in its swim bladder. Surface handling of the fish for release, including venting the swim bladder with a syringe and repositioning the stomach when everted, has resulted in only about 40–50% survival at the surface and an unknown additional mortality after release (Moffitt and Parrish[2]). The small size of the fish, 8–25 cm fork length (FL), adds a further complication by restricting acceptable transmitter size, which in turn limits battery life. A short battery life requires that collection of data representative of normal fish behavior begin at once and not be affected by buoyancy problems associated with an artificially vented swim bladder.

To prevent these problems with our acoustically tagged fish, we developed a subsurface handling method which is also applicable to other tagging and dietary study programs. The interception of hauled fish at an intermediate depth by divers offers the potential to prevent damaging barotrauma by minimizing expansion of the swim bladder.

Methods

Transmitter Placement

Because of the small size of our fish, we used the smallest available transmitter (approximately 8 mm diameter × 35 mm long) and restricted

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ABSTRACT—A method of handling hooked fish at intermediate depth was developed for species which occur deeper than conventional scuba depths. Juvenile pink snappers, Pristipomoides filamentosus, *were hauled from 65–100 m to a depth of only 30 m, where the ambient pressure change was a fraction of that produced by hauling fish to the sea surface. This method afforded a unique opportunity to acoustically tag deepwater, physoclistous fish without the need to alter the fish's original swim bladder volume and without the high risk of further injury associated with surface handling. Tagged* P. filamentosus *survived and behaved well and were tracked successfully. This basic method could be applied to a variety of deepwater species in a number of research approaches, including tagging and dietary studies.*

[1]DeMartini, E. E., A. M. Barnett, T. D. Johnson, and R. F. Ambrose. In review. Growth and production estimates for biomass-dominant fishes on a southern Californian artificial reef. Bull. Mar. Sci.

[2]Moffitt, R. B., and F. A. Parrish. Unpublished data on file at Honolulu Lab., Southwest Fish. Sci. Cent., Natl. Mar. Fish. Serv., NOAA, 2570 Dole Street, Honolulu, HI 96822-2396.

the size of our target fish to ≥15 cm FL. The transmitter was introduced orally and pushed down the esophagus of the fish by a small dowel (8 mm diameter × 18 cm long), equipped with a sleeve to hold the transmitter. Small barbs attached to the transmitter assisted in lodging and retaining it in the gut of the fish (Fig. 1). The time required to implant the transmitter never exceeded 5 seconds. The effects of tagging and tag retention were also evaluated in a tank experiment in which dummy transmitters were implanted in two juvenile snappers as described above and observed over a 3-week period.

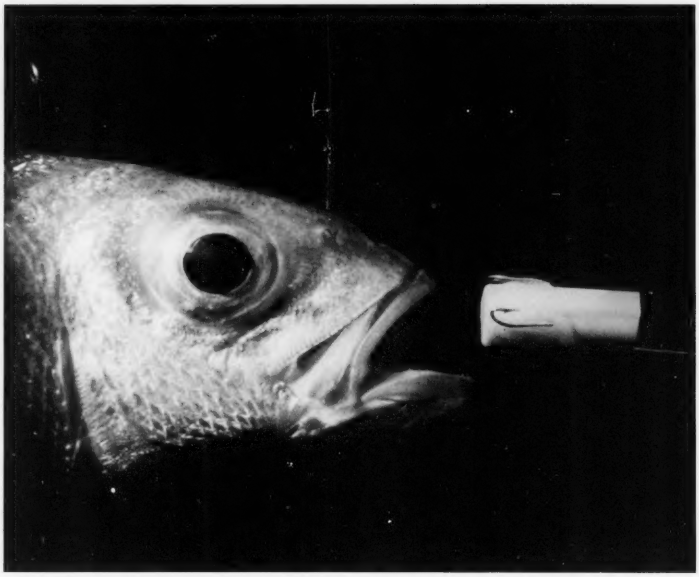

Figure 1.—An intragastric acoustic transmitter (35 mm long) being implanted in a juvenile pink snapper.

Subsurface Tagging Operations

The "tagging array" (Fig. 2) consisted of a polypropylene line connected to a rectangular wire trap (100 × 75 cm) which was suspended 30 m below a surface buoy loosely roped to a surface support vessel. Shock absorbing cords were affixed to the line at both the buoy and trap ends to minimize the effect of surface movement on the trap. Attached to the line 17 m below the surface was a T-bar where divers waited to intercept fishing lines hauled by fishermen in the boat.

When a fish was hooked, a fisherman reeled the monofilament line in until a premeasured depth mark on the line was reached. A carabiner was clipped around both the fishing line and a taut high-test monofilament "transport line" connected between the fishing boat and one end of the T-bar. The heavy carabiner slid down the transport line, pulling the fishing line close to the array and the waiting divers. The divers were then able to find the nearly invisible monofilament fishing line at the end of the T-bar and proceed with the tagging operations.

If the divers determined that the fish on the line was not suitable for tagging, a diver signaled the surface crew to continue fishing by clipping a particular color-coded buoy around the fishing line and freeing it from the T-bar. Once a suitable fish was hooked, they descended to the 30 m depth where the hooked fish hung suspended close to the wire holding trap. Wearing latex gloves to protect the fish, a

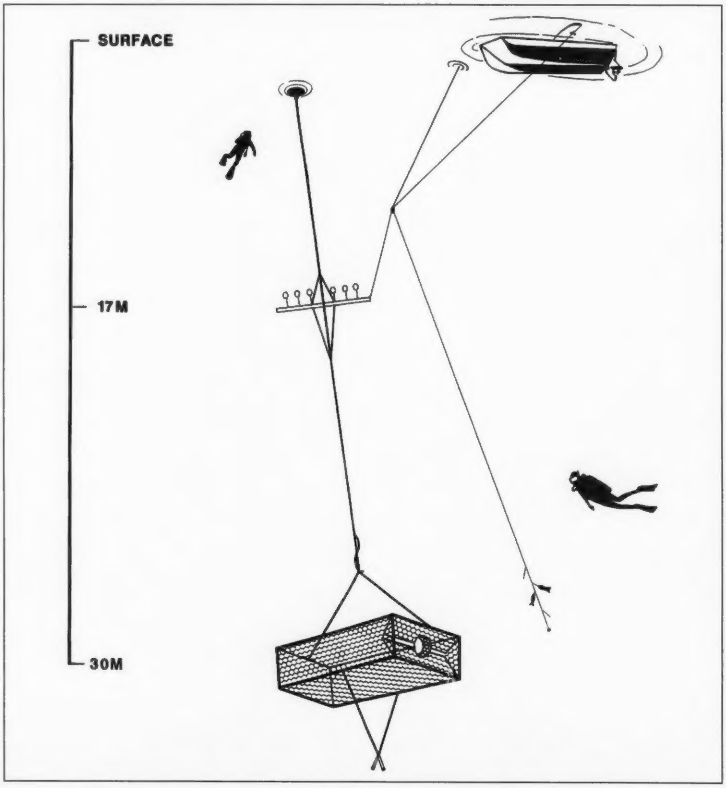

Figure 2.—Schematic representation of the subsurface tagging array.

diver restrained the fish while using the modified dowel to push the transmitter down its gullet. The fish was then removed from the hook, and its FL measured with a scale (mounted on the trap) as the fish was placed in the trap through an escape-proof entrance. The trap was lined with fine mesh synthetic netting to cushion the interior. Fishermen in the boat were signaled to stop fishing by clipping a different color-coded buoy to the empty fishing line and releasing it from the T-bar. Each tagged fish was held in the trap for about 5 minutes, allowing evaluation of its physical condition before release with the transmitter installed. If the appearance or behavior of the fish seemed questionable, the diver dissected the fish and recovered the transmitter for implantation in the next suitable fish. If the tagged fish demonstrated brisk activity and normal orientation in the trap, it was released by a hinged panel being opened on the trap (Fig. 3).

Results and Discussion

Using the methods described above, we successfully implanted tags in juvenile snappers on each of five trials. None of the 17 fish that were brought to 30 m from depths of 65–90 m had everted stomachs or other obvious symptoms of barotrauma. This is not unexpected because, assuming unrestricted gas expansion, a fish brought from 65 m to 30 m would experience 1.9-fold expansion of its swim bladder instead of a possible 7.5-fold expansion if it were brought to the surface. Ten fish were not selected for tagging: Some were too small (<15 cm FL), and others were hooked deep in the mouth and therefore risked damage to gills or esophagus when the hook was removed. Two of the seven fish tagged had poor color and experienced difficulty orienting while in the holding trap. They were sacrificed to recover the transmitters. The remaining five fish were successfully tagged and released. Released fish swam immediately toward the bottom.

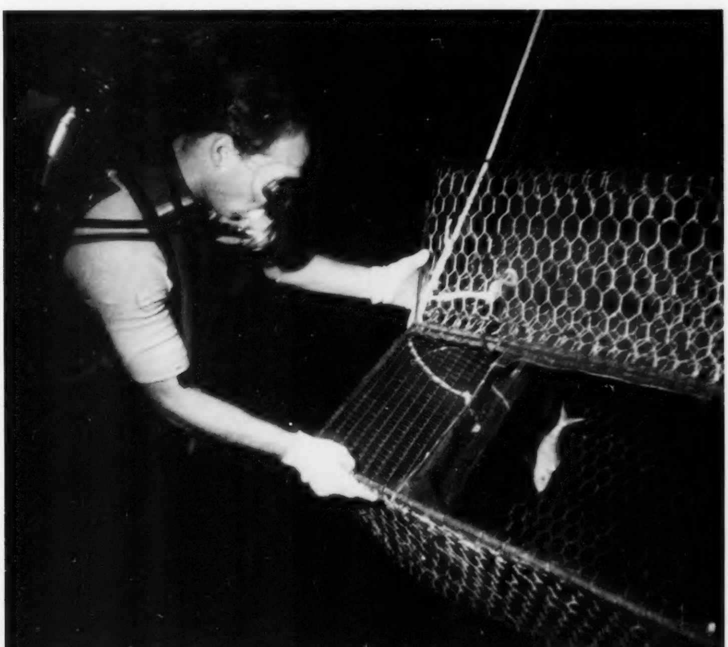

Figure 3.—Release of a juvenile pink snapper implanted with an acoustic transmitter at 30 m depth.

One of the two fish implanted with dummy transmitters in the holding tank died immediately. Death was probably due to internal injuries sustained when the transmitter was inserted. The second tagged fish in the tank study fed and behaved normally with the five conspecifics with which it was held throughout the 3-week period.

We elected to implant transmitters orally because of the ease of application by divers and the minimal handling time required. We anticipated success since others (McCleave and Stred, 1975; Hawkins and Urquart, 1983; Mellas and Haynes, 1985; Lucas and Johnstone, 1990) have reported minimally altered behavior of fish with gastric transmitter implants. Our resulting tracks, using this technique in our subsurface tagging, provided data with consistent behavioral trends over the 5-day duration of each track.

Our subsurface handling method has potential application to dietary and tag-release studies for a number of deepwater species. The need for such a technique and its effectiveness will probably vary with the depth of capture and the physiological tolerances of individual species. In dietary studies, fish could be removed from the hook and bagged at depth prior to regurgitation and stomach eversion, thus ensuring the integrity of the food sample. In tagging studies, including acoustic tracking, advantages include minimum handling (all in the water), reduced trauma from excessive swim bladder distension, avoidance of the effects of surgical puncture of the bladder, and opportunity to observe the condition of the fish before release. All these features increase the likelihood of releasing healthy, normal fish. However, the method is labor intensive (requiring a minimum of three people), and fishing time is limited by the time at depth safe for the divers. Therefore, the method may only be effective in situations where the target species can be caught readily.

Acknowledgments

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Editorial Guidelines for the *Marine Fisheries Review*

The *Marine Fisheries Review* publishes review articles, original research reports, significant progress reports, technical notes, and news articles on fisheries science, engineering, and economics, commercial and recreational fisheries, marine mammal studies, aquaculture, and U.S. and foreign fisheries developments. Emphasis, however, is on in-depth review articles and practical or applied aspects of marine fisheries rather than pure research.

Preferred paper length ranges from 4 to 12 printed pages (about 10-40 manuscript pages), although shorter and longer papers are sometimes accepted. Papers are normally printed within 4-6 months of acceptance. Publication is hastened when manuscripts conform to the following recommended guidelines.

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Submission of a manuscript to *Marine Fisheries Review* implies that the manuscript is the author's own work, has not been submitted for publication elsewhere, and is ready for publication as submitted. Commerce Department personnel should submit papers under a completed NOAA Form 25-700.

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Keep titles, heading, subheadings, and the abstract short and clear. Abstracts should be short (one-half page or less) and double-spaced. Paper titles should be no longer than 60 characters; a four- to five-word (40 to 45 characters) title is ideal. Use heads sparingly, if at all. Heads should contain only 2-5 words; do not stack heads of different sizes.

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In style, the *Marine Fisheries Review* follows the "U.S. Government Printing Office Style Manual." Fish names follow the American Fisheries Society's Special Publication No. 12, "A List of Common and Scientific Names of Fishes from the United States and Canada," fourth edition, 1980. The "Merriam-Webster Third New International Dictionary" is used as the authority for correct spelling and word division. Only journal titles and scientific names (genera and species) should be italicized (underscored). Dates should be written as 3 November 1976. In text, literature is cited as Lynn and Reid (1968) or as (Lynn and Reid, 1968). Common abbreviations and symbols such as mm, m, g, ml, mg, and °C (without periods) may be used with numerals. Measurements are preferred in metric units; other equivalent units (i.e., fathoms, °F) may also be listed in parentheses.

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